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**HOT MELT ADHESIVE PAD SURFACE ATTACHMENT ASSEMBLY CONCEPT  
FOR ON-ORBIT OPERATIONS**

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**FOR REFERENCE**

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## INTRODUCTION AND BACKGROUND

An important requirement for on-orbit operations to repair space vehicles or assemble large space structures will be the ability for the astronaut or robot to temporarily attach a work platform to a surface. This attachment must adhere readily to a variety of materials, including metals, fiber reinforced polymer matrix composites, and ceramics. The surfaces may be flat or have multiple curvature. The surface attachment assembly (SAA) should adhere and detach from the surface quickly, with a minimum of workload required by astronauts, and must provide adequate strength under tension, shear, and bending forces. Langley Research Center (LaRC) has investigated the use of a hot melt adhesive concept wherein the adhesive is impregnated into fiberglass pads containing electrical heating and thermoelectric cooling devices. The hot melt adhesive can be repeatedly heated to its melting point in vacuum and provides good adhesion when cooled, even to lightly contaminated surfaces. When the astronaut is ready to leave the work site, the adhesive is remelted by the pad and a small load provides the release from the work surface.

The hot-melt SAA described herein was designed specifically for one of the most demanding tasks of this type: repair of the fragile ceramic reusable surface insulation (RSI) tiles which provide the "acreeage" areas of the thermal protection system on the Space Shuttle orbiter<sup>(1-3)</sup>. Figure 1 shows a sketch of an astronaut in his manned maneuvering unit (MMU) and work restraint system (WRS) attached to the RSI tile surface of the Shuttle orbiter, repairing damaged tiles in orbit. The SAA must enable the repair to be made without damaging the fragile RSI tiles it attaches to. Figures 2 and 3 outline the detailed "needs and wants" of this application. Any proposed SAA concept must meet all the "needs" criteria for further

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consideration. The most promising (and thus the one developed into prototype assemblies) also satisfied most of the "wants" criteria.

The concept selected for most intensive development is shown on Figure 4. It evolved by the process of screening a series of commercially available hot melt adhesives, investigating alternate attachment concepts, fabrication of concept models, and testing of two prototype full-size units. This document provides a system description, assembly and disassembly procedures, an outline of system operations, and a section on test procedures and test results. Appendix A by Bruce D. Little gives a parts description and assembly procedure. Appendix B by R.H. Couch, A. W. Frizzell, and R. Fox describes the electronic systems and controls.

Further documentation may be found in 20 and 50 minute video tapes available from LaRC.

#### ADHESIVE AND SYSTEM CHARACTERISTICS

Jet-Melt 3746\*, the adhesive selected from a group of thermoplastic adhesives as a result of studies which will be discussed in the section "Test Procedures and Test Results", has limited information given in the product literature. Some of the physical characteristics listed are: light amber color; specific gravity, 0.96; viscosity, 6.2 Ns/m<sup>2</sup> (6250 cps) at 191°C (375°F), 1.75 Ns/m<sup>2</sup> (1750 cps) at 243°C (450°F); tensile strength, 7.2 MPa (1050 psi); elongation, 75%; and softening point, 124°C (255°F) (Ball and Ring), ASTM E-28-67. Information obtained from the vender identified

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\*Adhesive supplier's are indicated in Table 1.



the adhesive as a polyamide. This was verified by an infrared (IR) spectrographic analysis of the material. Jet-Melt 3746 was supplied as a cartridge approximately 76 mm (3 in.) long with a 25 mm (1 in.) diameter.

Visual observation of the adhesive during heating in a vacuum oven (approximately 47 hours at 80°C (176°C), low vacuum) showed no adverse effects--no outgassing was observed (i.e. no bubbles formed or foaming occurred). No weight loss occurred during the same exposure.

Considering the "needs criteria" (Figure 2), items 4, 5, and 8, which apply to the adhesive properties are certainly obtainable for Jet-Melt 3746. The adhesive has proven compatible with the RSI tile coating. Although our preliminary investigation included tests at room temperature and 82°C (180°F), there was no reason to believe it would not hold the required loads at -23°C (-10°F). That supposition was subsequently verified in tests at Johnson Space Center (JSC). The property of a thermoplastic to conform to the surface when soft would allow it to adhere to a surface with a 101-cm (40-in.) radius. Furthermore, as described subsequently, the 3-pad SAA unit, was designed such that each pad has a freedom of movement within limits which allows it to self-align to the RSI tile surface. The combination of the above allows the unit to readily attach to a 101-cm (40-in.) radius surface.

Listed in Figure 3 are some of the "wants" for an adhesive for the Work Restraint System Attachment Unit. Jet-Melt 3746 fulfilled those "wants" applying to the adhesive very well. Jet-Melt has the capability for repeated melt/remelt in vacuum at the same temperature each cycle. The adhesive softens/melts in the temperature range of interest 149°C (300°F). Depending on the pad arrangement and the temperature at release, minimal adhesive is left on the RSI tiles.

The polyamide adhesive remaining on the tiles would be vaporized due to the high temperatures encountered during reentry. Methods have been developed for simple and easy replenishment of the adhesive on the pad.

The shock absorber capability of the SAA was accounted for in the design of the pads, however, further shock absorber capability was acquired by the viscous properties of the adhesive. When the WRS comes in contact with the RSI tiles, the adhesive, heated to a soft consistency, acts as a cushion for the WRS. The loads to be encountered as the WRS approaches the tile surface have been determined to be minimal.

The need for the adhesive to be retained in some degree each time an attachment/separation was completed, so that the multiple attachment capability could be achieved, was the result of a series of pad surface design modifications. As a result, the adhesive was impregnated into fiberglass cloth as shown in Figure 5. This arrangement allowed the adhesive to move to the surface upon repeated melt/attachment/separation cycles. After several melt/attachment/separation cycles, the adhesive was depleted to such an extent that further attachment to the RSI tiles was questionable and therefore the pad must be recharged. The initial attempts to replenish or recharge the adhesive to the pad was accomplished by contacting the adhesive cartridge to the hot pad surface, allowing the adhesive to melt and rubbing the adhesive onto the pad. This proved to be difficult since the hot area of the pad is limited and attempts to keep the sticky adhesive in that restrained areas was a problem. This would be an almost impossible task for an astronaut to perform due to the bulky gloves worn during EVA and to the astronaut's limited movement.

Because of the difficulties an astronaut might experience with the rub-on technique, a method of recharging<sup>(4)</sup> the pad using a film patterned to match the hot area of the pad (determined by the size of the thermofoil heater underneath the impregnated fiberglass cloth, Figure 5) was developed. The design of the hot melt recharge system is shown in Figure 6. The system consists of a hot melt film (Jet-Melt 3746) sandwiched between a thin high temperature single-sided pressure-sensitive tape such as Kapton Tape No. 2345-2 (Dodge Fluoroglas Division) and thin teflon film such as Type C, 5 mil Teflon. The dimensional configuration shown are such to accommodate the present configuration of the hot area of the pads of the SAA. Teflon tabs were provided for gripping with the fingers, or, in space, with astronaut gloves. The primary purpose of the recharge tape concept for use in space was to hold the hot melt recharge film in place on the surface attachment pad until the film was melted and fused to the surface. The recharge procedure is given in Figure 7. Because the Jet-Melt 3746 was supplied in cartridge form, a method of making thin [0.5 mm (0.02 in.)] films was developed. The cartridge, 76 mm (3 in.) long by 25 mm (1 in.) diameter was cut into approximately 19 mm (0.75 in.) pieces. The press was preheated to about 130°C (265°F), a piece of adhesive was centered on a Kapton film resting on the bottom platen of the press which has 0.5 mm (0.20 in.) shims placed at the corners of the platen. Another Kapton film was placed on top of the adhesive. Pressure was applied slowly to the adhesive while increasing the temperature until the platens rested on the shims. The press was opened and the adhesive film, sandwiched between the Kapton film, was removed. The adhesive, when cooled, was separated from the Kapton films by flowing water between the Kapton films and pulling apart. The size of

the adhesive film produced from the 19 mm (0.75 in.) piece of adhesive was approximately 152 mm (6 in.) in diameter by 0.5 mm (0.02 in.) thick. The particular configuration to match the thermofoil heaters was cut out with a razor blade. Two holes were also cut from the film to eliminate adhesive from "cold spots" produced by the thermofoil heaters.

The adhesive recharge, as would be applied during an astronaut EVA, was evaluated in a vacuum and found to be a viable method. Gas entrapment does occur to a limited extent and care must be exercised when applying the film charge on the pad surface.

Tests conducted with a single pad have shown the gas entrapped during the initial adhesive impregnation can be eliminated by heating the impregnated pad overnight in a low vacuum.

## ADHESIVE EVALUATIONS

### Adhesive Screening

The adhesive for the SAA pads must adhere to the RSI tiles (actually the ceramic coating on the tiles) in the temperature range  $-23^{\circ}\text{C}$  to  $82^{\circ}\text{C}$  ( $-10^{\circ}\text{F}$  to  $180^{\circ}\text{F}$ ), must be stable in the space environment, must be capable of repeated melt/remelt cycles without any adverse property changes, must soften/melt at about  $149^{\circ}\text{C}$  ( $300^{\circ}\text{F}$ ), must have no or minimum outgassing, and must maintain adherence when a 220-N (50-lb) workload is applied [also a 88-N (20-lb) shear load]. The adhesive was needed to prove a concept, i.e. attach the WRS to the RSI tiles of the Shuttle Orbiter, and therefore this screening study was not as exhaustive as might be conducted.

Venders of commercial hot melt adhesives were contacted and given the above adhesive requirements, recommendations were solicited, and a number of hot melt adhesives were obtained (Table I). The type of polymer identified in Table I was the result of IR spectrographic analysis and information supplied by some of the venders.

## Procedures

### Physical Properties

A preliminary study of the softening characteristics of the adhesives was conducted using a Fisher-Johns Melting Point Apparatus and Thermomechanical Analysis equipment (DuPont 943 with the 990 Controller).

The effects of low vacuum and 80°C (176°F) on candidate adhesives was also studied. 2.5 to 3.0 grams (0.009 to 0.11 oz.) of adhesive were placed in aluminum pans, placed in a laboratory vacuum oven for 47 hours and observed. Indications of outgassing, i.e. foaming or bubbles, were observed for some of the adhesives. Weight change, if any, was determined for the above exposure.

### Mechanical Properties

Preliminary tests were conducted with Polyshot 804 (polyamide) using flatwise tensile type specimens consisting of 5.1 cm by 5.1 cm (2 in. by 2 in.) RSI tiles (with ceramic coating) about 1.3 cm (0.5 in.) thick bonded to aluminum blocks with RTV 560 (General Electric). The tiles were bonded together with Polyshot 804. Tests were conducted using an Instron Testing Machine with a quartz-lamp clam-shell heating oven. The sequence of testing involves applying a 34 kPa (5 psi) tension load at room temperature, holding for one minute and releasing the load; heating to 149°C (300°F), separating the tiles, cooling to about 49°C (120°F); reheat to 149°C (300°F),

contacting the tiles together under minimal loading, cooling to 82°C (180°F), and applying load. Failure occurred when the tile coating pulled off. The test did prove that the polyamide adhesive bonded to the tile coating. However, due to the failure of the tile coating, the test was discontinued.

Further tests were conducted using a single pad with several modifications of the method for heating the adhesive as well as modifications in the pad arrangement. Examples are shown in Figures 8 and 9. Using these arrangements, the adhesive was heated on the pad and brought into contact with the RSI tile. Load requirements as set by the end application were 34 kPa (5 psi) tension load and a contact pressure of 14 kPa (2 psi). Tests were conducted to determine the "best" temperature for bonding, multiple "stick" capability, the effect of cool-down time (which in effect determines the approximate temperature with load carrying capability), and heat-up rate. All tests were conducted at ambient conditions unless otherwise specified.

#### Test Results

Results of measurements with the Fisher-Johns Melting Point Apparatus and TMA indicated that the polyamides possessed the necessary softening/melt characteristics for the intended purpose of this study. Softening was in the range of 121°C to 149°C (250°F to 300°F). Other systems also possessed softening in a similar temperature range, but were eliminated for reasons to be discussed subsequently.

The results of a study to determine the effects of low vacuum and 80°C (176°F) on several candidate adhesives is given in Table II. Based on their stability (minimal weight loss and foaming), Jet-Melt 3746 and Plastilock

801 appeared to be the most promising candidates. Plastilock 801 does not flow as well as Jet-Melt nor can it be easily impregnated into fiberglass cloth for actual use in the SAA pad. Other "stick" tests conducted proved that many of the hot melt adhesives did not adhere to the RSI tile coating.

Multiple "stick" capability, "best" temperature for bonding and the effect of cool down time are given in Table III. At the time these tests were conducted, the goal specified for multiple sticks was five (5). The results show this to be achieved using the following conditions for the particular pad arrangement used: adhesive (Jet-Melt 3746) temperature of 163°C (325°F) and a 45 second cool down [the temperature after this cool down period should be less than 82°C (180°F)]. Obviously the cool down rate as well as the heatup rate is a function of the SAA pad arrangement and other factors. Tests were conducted with other pad arrangements that indicated similar results.

## SYSTEM DEVELOPMENT

### Procedures

After considerable iteration of the needs, wants, and possibilities for this SAA, the 3-pad assembly (Figure 4) using an aluminum alloy frame, fiberglass pads impregnated with the Jet-Melt 3746 adhesive, thermofoil heaters, thermoelectric coolers, and an aluminum alloy heat sink, with state-of-the-art solid state electronic controls, was designed and prototyped. Mechanical details of this system are given in Appendix A, electronic systems and controls are detailed in Appendix B.

The final design of the single pad is shown in Figures 5 and 10. Tests were conducted with this pad for Jet-Melt 3746 to determine multiple stick capability as well as load-at-separation. Direct Current (D.C.) power supplies were used for the thermofoil heating elements and thermoelectric cooling unit. A typical temperature and load time-history is given in Figure 11 and the test procedure is given in Figure 12. Results will be discussed later.

Once the results of the single pad studies confirmed the concept, a full size 3-pad engineering development SAA system was fabricated. This is shown in Figure 13. Previously, the heatup and cool down were controlled manually using D. C. power supplies. Subsequently, a temperature controller was designed and integrated into the SAA system. Tests with this system were conducted by attachment to and detachment from a wall of six (6) RSI tiles. Typical temperature, power, and load histories are shown in Figure 14 and the test procedure given in Figure 15 and a sketch of the test system shown in Figure 16. Several tests were conducted with this system. The SAA system must attach to a flat surface of RSI tiles and tile surfaces with steps as large as 2.5 mm (0.1 in.). Loads greater than specified were investigated to show overload capabilities of the SAA system.

Studies were also conducted at Johnston Space Center to further qualify the concept for Space Shuttle applications and to transfer the LaRC, Hot Melt Adhesive SAA concept models and technology to JSC personnel. The primary objective of the tests was to demonstrate the capability of the SAA to adhere to RSI at the limits of its design range. Secondary objectives were to evaluate adhesion and release at sub-zero temperatures to RSI in vacuum and to determine the capabilities and limitations of the concept for



attachment to large space structure components of advanced composite materials and aluminum. Figure 17 shows the JSC Chamber N facility in which the tests were conducted. The arrangement of the test equipment in the chamber is shown in Figure 18 and a 3-pad SAA (under 35 lb load) is shown attached to the RSI tile wall in Figure 19.

### Results

To determine the capability of the last prototype design of the single SAA pad, tests were conducted at 163°C (325°F) for multiple sticks. Table IV gives the pertinent information along with the test results. The goal of five (5) sticks was achieved by the system. A "stick" consisted of holding 34 kPa (5 psi) load for ten (10) minutes at temperatures less than 82°C (180°F). This was accomplished using a single charge of Jet-Melt 3746 adhesive. Also noted is the load-at-separation which decreased with successive sticks from 15.2 kPa to 4.1 kPa (2.2 psi to 0.6 psi). The goal for the load-at-separation had previously been specified as 4.4N (1 lb) per single pad or 2.8 kPa (0.4 psi) for the pad design of this study. Later results of tests with the 3-pad system met this criteria successfully. Failure of the sixth stick was due to a 30-second cool down at which time the adhesive temperature was 99°C (210°F) and still viscous.

Attachment to the RSI using the 3-pad system was straightforward, proving the self-aligning capability of the individual pads. In two repeated sticks with the single adhesive charge, the assembly held at 159 (35 lb) tensile load for the test period of 10 minutes without failure. Release of the assembly was achieved within 10 seconds under a 0.7 kg (1.5 lb) load [3.4 kPa (0.5 psi) per pad].

After an adhesive recharge, the SAA held a 227 kg (50 lb) tensile load for 10 minutes without failure. On the second stick with the remaining adhesive from the previous test, the 227 kg (50 lb) load resulted in release of the SAA after 4.5 minutes, with no RSI tile damage.

Tests of the hot melt SAA model were then conducted on a tile configuration with a 2.5 mm (0.1 in.) step between two tiles under one of the three pads. Thus there was full adhesive contact on two pads and partial contact on the third pad. The SAA held 159 kg (35 lb) tensile load for the full ten (10) minutes on the first stick without failure, but only for six (6) minutes before failure occurred on the second stick. For additional testing of this type, RSI tile coating damage was found to occur if peeling action under load became excessive.

Should the thermofoil heaters fail to function, an emergency release of the SAA was demonstrated. This was accomplished by using the thermoelectric cooler elements in the heating mode. Although more power and time was required to heat the adhesive to softening temperature, the emergency release method was successfully demonstrated for the 3-pad SAA.

These tests were conducted to prove the feasibility of the SAA concept and the adhesive selected, Jet-Melt 3746, was shown to meet the requirements of this concept. Other hot melt adhesives might be as good or better for the intended purpose and there are many more commercial adhesives available other than those investigated.

The preliminary results of the tests conducted at JSC are shown on the attached Tables IV-IX. In all cases except test 4, adherence under the 35 lb load occurred either fully on all 3 pads or in two cases (tests 8 and 9) on one or two pads of the SAA concept model. In the latter tests, lack of

adherence was completely explainable by a control point temperature in the pad being below 149°C (300°F). Adjusting that control point provided the required adherence in the next test. In the case of Test 4, further investigation indicated that the smooth face of the composite panel probably contained either a silicone or teflon parting compound which would prevent adherence of any adhesive. Although adherence could have been achieved by mechanically abrading the surface, this was not considered practical in space and was thus not included in the tests. In fact, no attempt was made to avoid light contamination due to fingerprints, etc. on the test panel surface or adhesive recharges, to maintain a realistic repair situation.

The test results were positive. The LaRC Hot Melt SAA system adhered readily to RSI tiles in vacuum at temperatures down to -34°C (-30°F). Adherence was also demonstrated on an 8-ply graphite fiber reinforced epoxy panel in vacuum from room temperature to -34°C (-30°F) and an 0.4-mm (0.016-in.) thick aluminum panel from room temperature to -10°C (0°F).

Several potential applications were discussed among the LaRC and JSC personnel including use on a Work Restraint System/Manned Maneuvering Unit for an astronaut to determine Spray on Foamed Insulation Thermal Protection System (SOFI TPS) degradation on the external tank of Shuttle and use on a remote manipulator arm to attach to spacecraft which require retrieval from space to the Shuttle payload bay.

Several areas of potential upgrading of the current LaRC Hot Melt Adhesive SAA concept were evident from the tests. These included minimizing the distance between pad heaters and thermoelectric coolers plus redesigning the heat sinks to obtain faster cool down rates, resetting pad temperature

control points, and lightening the aluminum structure of the SAA. These are all refinements of the prototype system.

## SUMMARY

Langley Research Center has investigated the use of a hot melt adhesive concept to develop a surface attachment assembly (SAA) for on-orbit attachment and detachment operations for the manned maneuvering unit (MMU). The concept involved impregnation of the hot melt adhesive into a fiberglass covered pad which contained electrical heating and thermoelectric cooling devices. The polyamide hot melt adhesive selected can be repeatedly heated to its melting point in a vacuum and provided good adhesion to various surfaces, i.e. reusable surface insulation tiles, metals, and composites, when cooled.

A number of the "needs" and "wants" for the work restraint system attachment unit have been achieved.

After a series of adhesive screening tests, Jet-Melt 3746, was selected from a group of commercially available thermoplastic adhesive candidates which met or exceeded many of the criteria established for the SAA system.

The SAA system was designed and fabricated at LaRC with the goal of proving the concept with a working model rather than attempting to optimize all facets of the system. This system evolved by investigating alternate attachment concepts, designing and fabricating electronic systems to heat and cool the adhesive, and then fabricating and testing two prototype full-size units.

Further documentation may be found in 20 and 50 minute video tapes available from LaRC.

#### ACKNOWLEDGEMENTS

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TABLE I. - CANDIDATE HOT MELT ADHESIVES

POLYAMIDES

JET-MELT 3746 (3M)  
POLYSHOT 804 (ORNSTEEN CHEMICAL)  
MACROMELT 6240 (HENKEL ADHESIVES)  
64 x 212 (GENERAL ADHESIVES & CHEMICAL COMPANY)  
INSTAWELD 34-3139 (GENERAL ADHESIVES & CHEMICAL COMPANY)

POLYPROPYLENES

EASTOBOND A 148S (EASTMAN CHEMICAL PRODUCTS, INC.)  
64 x 437 (GENERAL ADHESIVES & CHEMICAL COMPANY)

ACRYLIC ACID ETHYLENE COPOLYMER

SCOTCH-WELD 4060 (3M)

ETHYL VINYL ACETATES

NICOLMELT P-1022 (MALCOLM NICOL & CO., INC.)  
SEARS HOT MELT (SEARS ROEBUCK)  
HOT MELT NO. 200 (NICHOLSON & COMPANY)

MISCELLANEOUS

NICOMELT P-1580 (MALCOLM NICOL & CO., INC.)  
PLASTILOCK 801 (B. F. GOODRICH COMPANY)  
NUMEL 610 (GULF ADHESIVES)

POLYSTYRENE-POLYPROPYLENE COPOLYMER

HOT MELT 9011 (BOSTIC DIVISION, USM CORP.)

TABLE II. - EFFECT OF VACUUM AND THERMAL EXPOSURE<sup>a</sup> ON  
CANDIDATE ADHESIVES

SAMPLE	TOTAL WT. LOSS %	VISUAL OBSERVATIONS <sup>b</sup>
JET-MELT 3746	0	NO CHANGE
64 x 212	3.2	SLIGHT FOAMING
EASTOBOND A-148S	0.9	NO CHANGE
64 x 437	0.8	NO CHANGE
HOT MELT NO. 200	0.4	SLIGHT FOAMING
SCOTCH-WELD 4060	1.6	NO CHANGE
PLASTILOCK 801	0	NO CHANGE
NUMEL 610	1.3	FOAMED
HOT MELT 9011	1.8	FOAMED
SEARS HOT MELT	0	FOAMED
NICOLMELT P-1580	1.7	FOAMED
NICOLMELT P-1022	0.4	NO CHANGE

<sup>a</sup> 47 Hrs in vacuum oven at 80°C (176°F)

<sup>b</sup> NO CHANGE indicates flow/melt, but no bubbles or foaming



TABLE III.- "STICK"<sup>a</sup> TEST RESULTS FOR JET-MELT 3746

ADHESIVE CONTACT TEMP. <sup>b</sup> °C (°F)	TIME TO HEAT TO TEMP.	TIME OF COOL DOWN <sup>c</sup> SEC	NUMBER OF STICKS	COMMENTS
149 (300)	1 min 45 sec to 2 min 15 sec	15	1	New charge, failed on 2nd attempt.
149 (300)	1 min 45 sec to 2 min	30	4	Remaining adhesive, contact area 5% to 3%, 5th attempt failed.
163 (325)	1 min 48 sec to 2 min	15	1	New charge, failed on 2nd attempt.
163 (325)	2 min 20 sec to 3 min	30	0	Remaining adhesive, failed
163 (325)	2 min 10 sec to 2 min 20 sec	45	5	Remaining adhesive, contact areas 30% to 5%.

a "STICK" identified as maintaining a 34 kPa (5 psi) tension load for 10 min. Temperatures of thermoelectric cooler and hot melt surface at start of test were  $\leq 35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ).

b Contact pressure of 14 kPa (2 psi).

c Time of cool down while in contact before 34 kPa (5 psi) tensile load applied.

TABLE IV. - RESULTS OF SINGLE PAD MULTIPLE STICK TESTS  
WITH JET-MELT 3746

NO. OF STICKS <sup>a</sup>	TEMP. AT 45 SEC COOLING °C (°F)	MAINTAIN 34 kPa FOR 10 MIN AT 49°C (120°F)	SEPARATION TEMP. °C (°F)	INITIAL LOAD AT SEPARATION kPa (PSI)	COMMENTS
1	82 (180)	YES	163 (325)	15.2 (2.2)	New charge, contact area ~ 90%.
2	82 (180)	YES	163 (325)	9.6 (1.4)	Remaining adhesive, contact area ~ 80%.
3	79 (175)	YES	163 (325)	10.3 (1.5)	Remaining adhesive, contact area ~ 60%.
4	79 (175)	YES	163 (325)	6.9 (1.0)	Remaining adhesive, contact area ~ 30%.
5	82 (180)	YES	163 (325)	4.1 (0.6)	Remaining adhesive, contact area ~ 15%.
6	99 (210) <sup>b</sup>	NO	--	--	Remaining adhesive. Contact area ~ 0%.

<sup>a</sup> Adhesive held at 163°C (325°F) for 1 min before 14 kPa (2 psi) contact.

<sup>b</sup> Temperature at 30 sec cooling.

TABLE V. - RESULTS OF COLD VACUUM TESTS OF LaRC HOT MELT ADHESIVE  
SURFACE ATTACHMENT ASSEMBLY CONCEPT MODEL

(Tests Conducted in Johnson Space Center Chamber N)<sup>a</sup>

Test Number	Test Surface	Test Surface Attachment Temperature, °C (°F)	Chamber Pressure, torr	Heat-up <sup>b</sup> Time to 3-Pad Cycling, min	Heating Time on Test Surface, min	Cooldown Time to Load Application, min	Load Application Temperature on Adhesive Pads °C (°F)	Heat-up <sup>b</sup> Time for Pad Release Cycle, min	Release <sup>c</sup> Cycle Maximum Load, lbs	Remarks
1	RSI Tile Wall	24 (75)	2x10 <sup>-5</sup>	~1.0	0	4.5	85 (185)	~1.0	6	Successful; proved operation within design envelope.
2	RSI Tile Wall	-15 to -12 (5 to 10)	5x10 <sup>-5</sup> <sup>d</sup>	~1.0	0	4.0	85 (185)	~1.0	5	Successful; proved operation to low temperature limits of design envelope.
3	RSI Tile Wall	-40 to -34 (-40 to -30)	2x10 <sup>-4</sup> <sup>d</sup>	1.5	0	2.5	82 (180)	1.7	6	Successful; - Proved subzero temperature operation outside design envelope - Electronics operated cold but pad B had control point drift of 14°C.

<sup>a</sup> All attachments made at -14 lbs, followed by rapid load release. After pad cooldown, +35 lb load applied, held for 10 min, load released, reapplied for 1 min, load released.

<sup>b</sup> Heatup for pad release cycle from test surface conducted with -0.5 to -2 lb load.

<sup>c</sup> Followed by allowing pads to cycle for 1 min to equilibrate temperature.

<sup>d</sup> Release was generally in a rapid loading mode.

<sup>d</sup> Nitrogen leaks from cryopanel limited vacuum. However, molecular flow conditions were maintained.

TABLE VI. - RESULTS OF COLD VACUUM TESTS OF LaRC HOT MELT ADHESIVE  
SURFACE ATTACHMENT ASSEMBLY CONCEPT MODEL

(Tests Conducted in Johnson Space Center Chamber N)<sup>a</sup>

Test Number	Test Surface	Test Surface Attachment Temperature, °C (°F)	Chamber Pressure, torr	Heat-up <sup>b</sup> Time to 3-Pad Cycling, min	Heating Time on Test Surface, min	Cooldown Time to Load Application, min	Load Application Temperature on Adhesive Pads °C (°F)	Heat-up <sup>b</sup> Time for Pad Release Cycle, min	Release <sup>c</sup> Cycle Maximum Load, lbs	Remarks
4	8-ply Graphite/Epoxy Composite; Smooth Face	24 (75)	2x10 <sup>-5</sup>	~1.0	1.0	4.5	85 (185)	---	---	Failed at +20 lb load. Test surface may have silicone or Teflon release agent. Heavy adhesive charge.
4A	8-ply Graphite/Epoxy Composite; Rough Face	24 (75)	7x10 <sup>-5</sup>	1.2	1.5	8.0	77 (170)	1.1	3	Successful adhesion. Composite panel deflection was approximately 0.2 in. under applied load.

<sup>a</sup> All attachments made at -14 lbs, followed by rapid load release. After pad cooldown, +35 lb load applied, held for 10 min, load released, reapplied for 1 min, load released.

Heatup for pad release cycle from test surface conducted with -0.5 to -2 lb load.

<sup>b</sup> Followed by allowing pads to cycle for 1 min to equilibrate temperature.

<sup>c</sup> Release was generally in a rapid loading mode.

<sup>d</sup> Nitrogen leaks from cryopanel limited vacuum. However, molecular flow conditions were maintained.

TABLE VII. - RESULTS OF COLD VACUUM TESTS OF LaRC HOT MELT ADHESIVE  
SURFACE ATTACHMENT ASSEMBLY CONCEPT MODEL  
(Tests Conducted in Johnson Space Center Chamber N)<sup>a</sup>

Test Number	Test Surface	Test Surface Attachment Temperature, °C (°F)	Chamber Pressure, torr	Heat-up <sup>b</sup> Time to 3-Pad Cycling, min	Heating Time on Test Surface, min	Cooldown Time to Load Application, min	Load Application Temperature on Adhesive Pads °C (°F)	Heat-up <sup>b</sup> Time for Pad Release Cycle, min	Release <sup>c</sup> Cycle Maximum Load, lbs	Remarks
5	8-ply Graphite/Epoxy Composite; Rough Face	-12 (10)	2x10 <sup>-4</sup> <sup>d</sup>	1.3 ?	2.0	?	77 (170)	1.5	6	Successful adhesion. Adhesive removal difficult, indicating strong bond.
6	8-ply Graphite/Epoxy Composite; Rough Face	-40 to -32 (-40 to -25)	4x10 <sup>-4</sup> <sup>d</sup>	1.5	2.0	3.0 ?	77 (170)	1.5	7	Successful adhesion. Additional 5 min, +35 lb load application on adhesive below its 10°C (50°F) T <sub>g</sub> . Additional 1 min, +50 lb load application. All pads continued to adhere.

<sup>a</sup> All attachments made at -14 lbs, followed by rapid load release. After pad cooldown, +35 lb load applied, held for 10 min, load released, reapplied for 1 min, load released.

Heatup for pad release cycle from test surface conducted with -0.5 to -2 lb load.

<sup>b</sup> Followed by allowing pads to cycle for 1 min to equilibrate temperature.

<sup>c</sup> Release was generally in a rapid loading mode.

<sup>d</sup> Nitrogen leaks from cryopanels limited vacuum. However, molecular flow conditions were maintained.

TABLE VIII. - RESULTS OF COLD VACUUM TESTS OF LaRC HOT MELT ADHESIVE  
SURFACE ATTACHMENT ASSEMBLY CONCEPT MODEL

(Tests Conducted in Johnson Space Center Chamber N)<sup>a</sup>

Test Number	Test Surface	Test Surface Attachment Temperature, °C (°F)	Chamber Pressure, torr	Heat-up <sup>b</sup> Time to 3-Pad Cycling, min	Heating Time on Test Surface, min	Cooldown Time to Load Application, min	Load Application Temperature on Adhesive Pads °C (°F)	Heat-up <sup>b</sup> Time for Pad Release Cycle, min	Release <sup>c</sup> Cycle Maximum Load, lbs	Remarks
7	0.016 in. Thick Aluminum Alloy Panel	24 (75)	4x10 <sup>-5</sup>	1.6	1.5	2.5	77 (170)	2.0	17	Good adherence. Aluminum panel buckled and distorted under load. Longer release heating desirable. Residual adhesive removal difficult.
8	0.016-in. Thick Aluminum Alloy Panel	-12 (10)	2x10 <sup>-4</sup> <sup>d</sup> ?	2.0	2.0	2.5	77 (170)	2.5	?	Temperature control point drift in pads A and B. Adherence on pad C only but +35 lb load maintained.

- <sup>a</sup> All attachments made at -14 lbs, followed by rapid load release. After pad cooldown, +35 lb load applied, held for 10 min, load released, reapplied for 1 min, load released.
- <sup>b</sup> Heatup for pad release cycle from test surface conducted with -0.5 to -2 lb load.
- <sup>c</sup> Followed by allowing pads to cycle for 1 min to equilibrate temperature.
- <sup>d</sup> Release was generally in a rapid loading mode.
- <sup>d</sup> Nitrogen leaks from cryopanel limited vacuum. However, molecular flow conditions were maintained.

TABLE IX. - RESULTS OF COLD VACUUM TESTS OF LaRC HOT MELT ADHESIVE  
SURFACE ATTACHMENT ASSEMBLY CONCEPT MODEL

(Tests Conducted in Johnson Space Center Chamber N)<sup>a</sup>

Test Number	Test Surface	Test Surface Attachment Temperature, °C (°F)	Chamber Pressure, torr	Heat-up <sup>b</sup> Time to 3-Pad Cycling, min	Heating Time on Test Surface, min	Cooldown Time to Load Application, min	Load Application Temperature on Adhesive Pads °C (°F)	Heat-up <sup>b</sup> Time for Pad Release Cycle, min	Release <sup>c</sup> Cycle Maximum Load, lbs	Remarks
9	0.010 in Thick Aluminum Alloy Panel	-21 to -18 (-5 to 0)	4x10 <sup>-4</sup> <sup>d</sup> ?	2.3	4.0	2.3	77 (170)	3.5	8.5	Temperature control point drift in pad B. Adherence on all pads for 9 min; then pads B and C popped loose. Load released and pads reheated for reattach. Pad C reattached and pads A and C held +35 lbs for 3.5 min before release cycle initiated.

<sup>a</sup> All attachments made at -14 lbs, followed by rapid load release. After pad cooldown, +35 lb load applied, held for 10 min, load released, reapplied for 1 min, load released.

Heatup for pad release cycle from test surface conducted with -0.5 to -2 lb load.

<sup>b</sup> Followed by allowing pads to cycle for 1 min to equilibrate temperature.

<sup>c</sup> Release was generally in a rapid loading mode.

<sup>d</sup> Nitrogen leaks from cryopanel limited vacuum. However, molecular flow conditions were maintained.

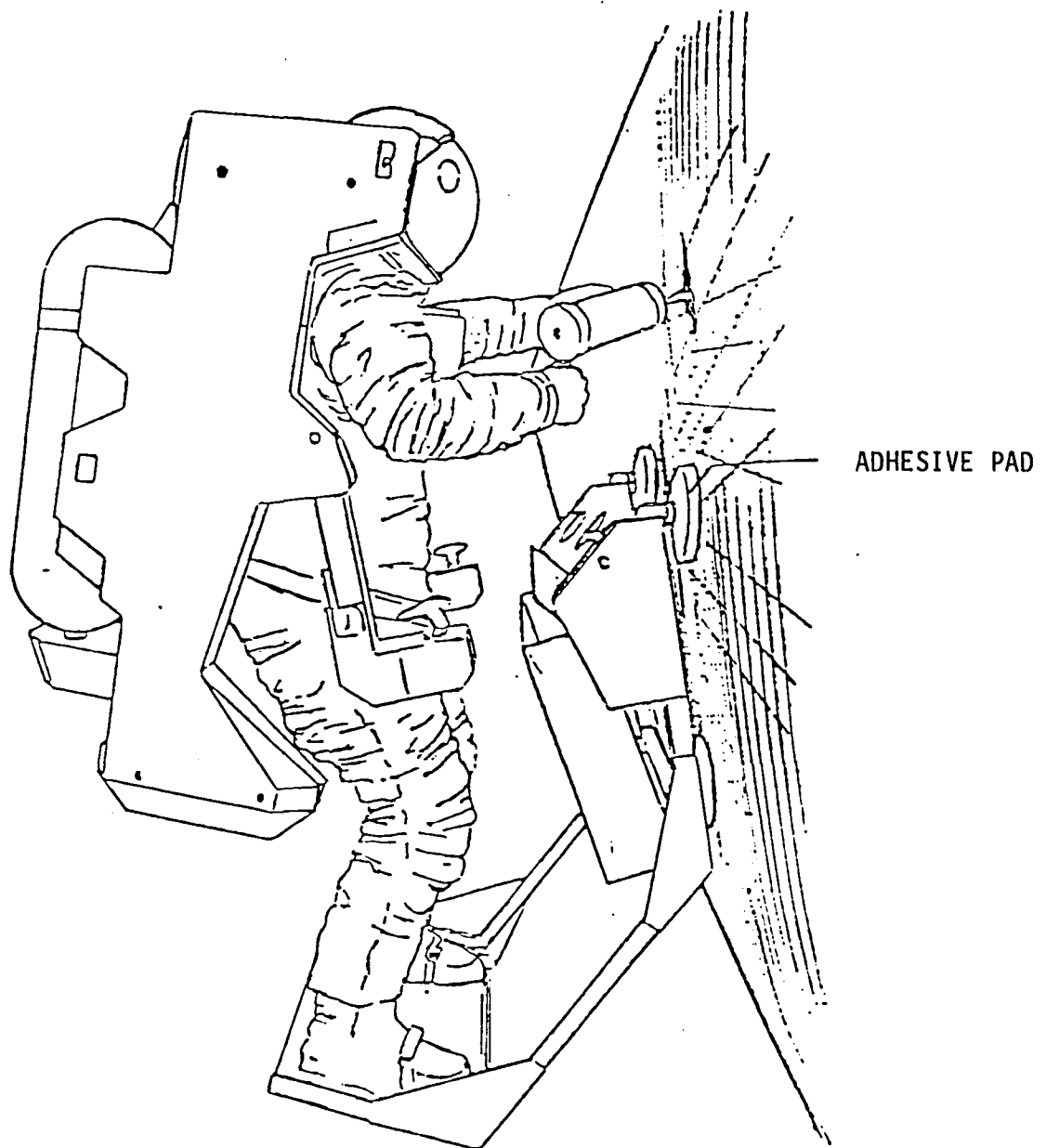


Figure 1.- On-orbit thermal protection system repair.



## WORK RESTRAINT SYSTEM ATTACHMENT UNIT CRITERIA

### NEEDS

1. REACT MAXIMUM FORCES APPLIED BY ASTRONAUT TO ORBITER SURFACE DURING REPAIR WITHOUT ADHESIVE, RSI TILE, OR UNIT STRUCTURAL FAILURE
  - 50 TO 150 lbs TENSILE
  - 20 TO 60 lbs SHEAR
2. GENERATES < 5 PSI ON ORBITER TILE SURFACE DURING WORK RESTRAINT SYSTEM (WRS) ATTACHMENT, DETACHMENT, OR ASTRONAUT REPAIR ACTIVITY
3. COMPATIBLE WITH 75 TO 100 VOLT, 300 WATT-HOUR BATTERY POWER AVAILABLE ON WORK RESTRAINT SYSTEM
4. ADHESIVE COMPATIBLE WITH RSI TILE COATINGS
5. ADHERE TO ORBITER SURFACE AT TEMPERATURES FROM -23 TO 82°C (-10 TO 180°F)
6. RESULTS IN < 4 SEC OF MANNED MANEUVERING UNIT THRUST PER ATTACHMENT
7. 2 OR 3 ATTACHMENT UNITS
8. ADHERE TO COMPOUND CURVATURE OF 40-IN. RADIUS
9. LOW FAILURE PROBABILITY

Figure 2. - Work restraint system attachment criteria - needs.

## WORK RESTRAINT SYSTEM ATTACHMENT UNIT CRITERIA

### WANTS

1. ADHESIVE MELT/REMELT CAPABILITY IN VACUUM AT SAME TEMPERATURE
2. ADHESIVE SOFTENING/MELTING TEMPERATURE ABOUT 149°C (300°F)
3. MINIMAL ADHESIVE RESIDUE ON RSI TILES
4. DETACH WRS FROM ORBITER WITH NO MMU PROPELLANT
5. ADHESIVE RESIDUE ON TILES VAPORIZE EARLY IN REENTRY CYCLE
6. LESS THAN 100 WATT-HOURS NEEDED FOR EACH PAD FOR TOTAL ON-ORBIT REPAIR TASK
7. SIMPLE ADHESIVE REPLENISHMENT
8. SHOCK ABSORBER CAPABILITY

Figure 3. - Work restraint system attachment criteria - wants.

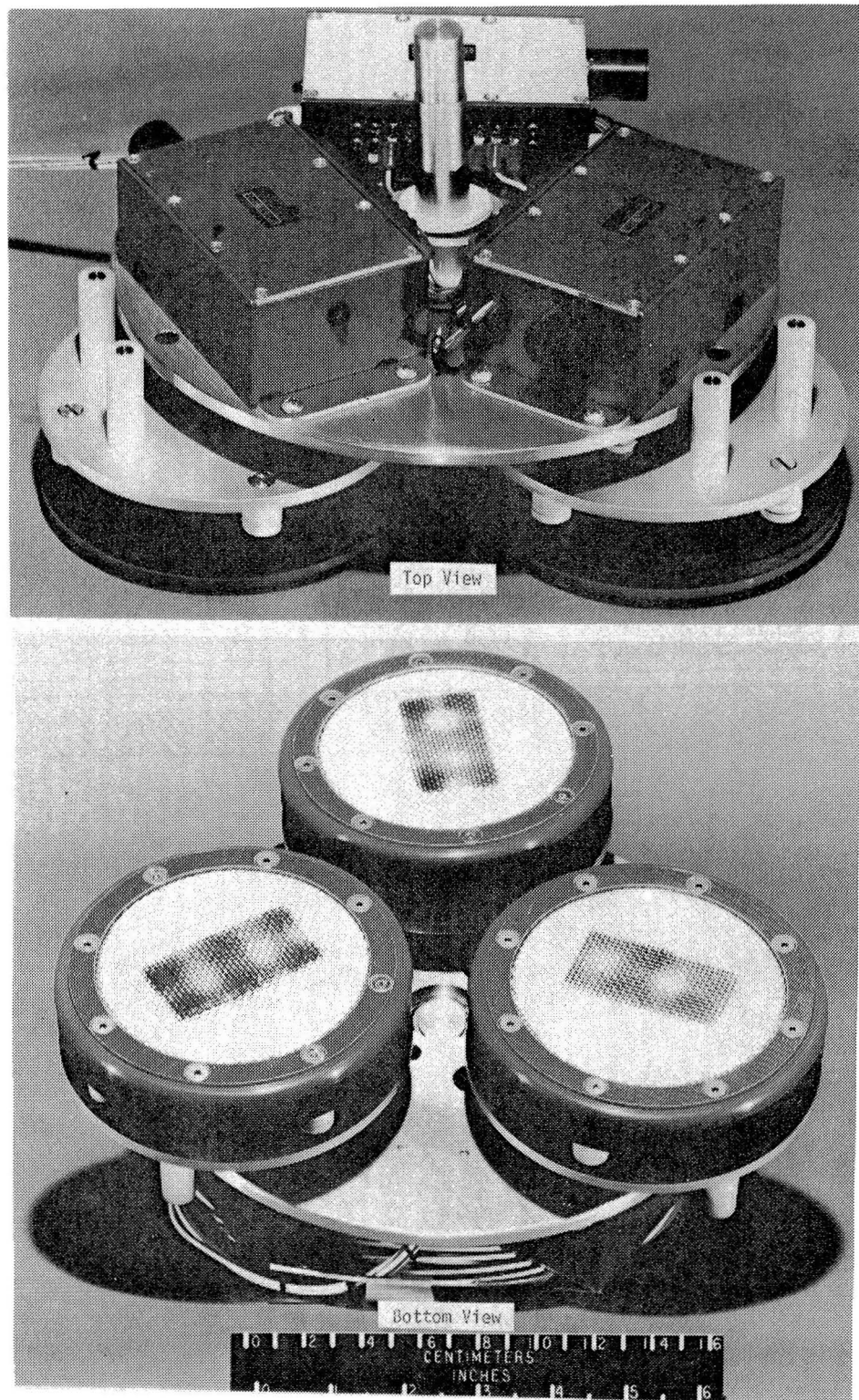


Figure 4.- 3-pad hot melt adhesive surface attachment assembly.

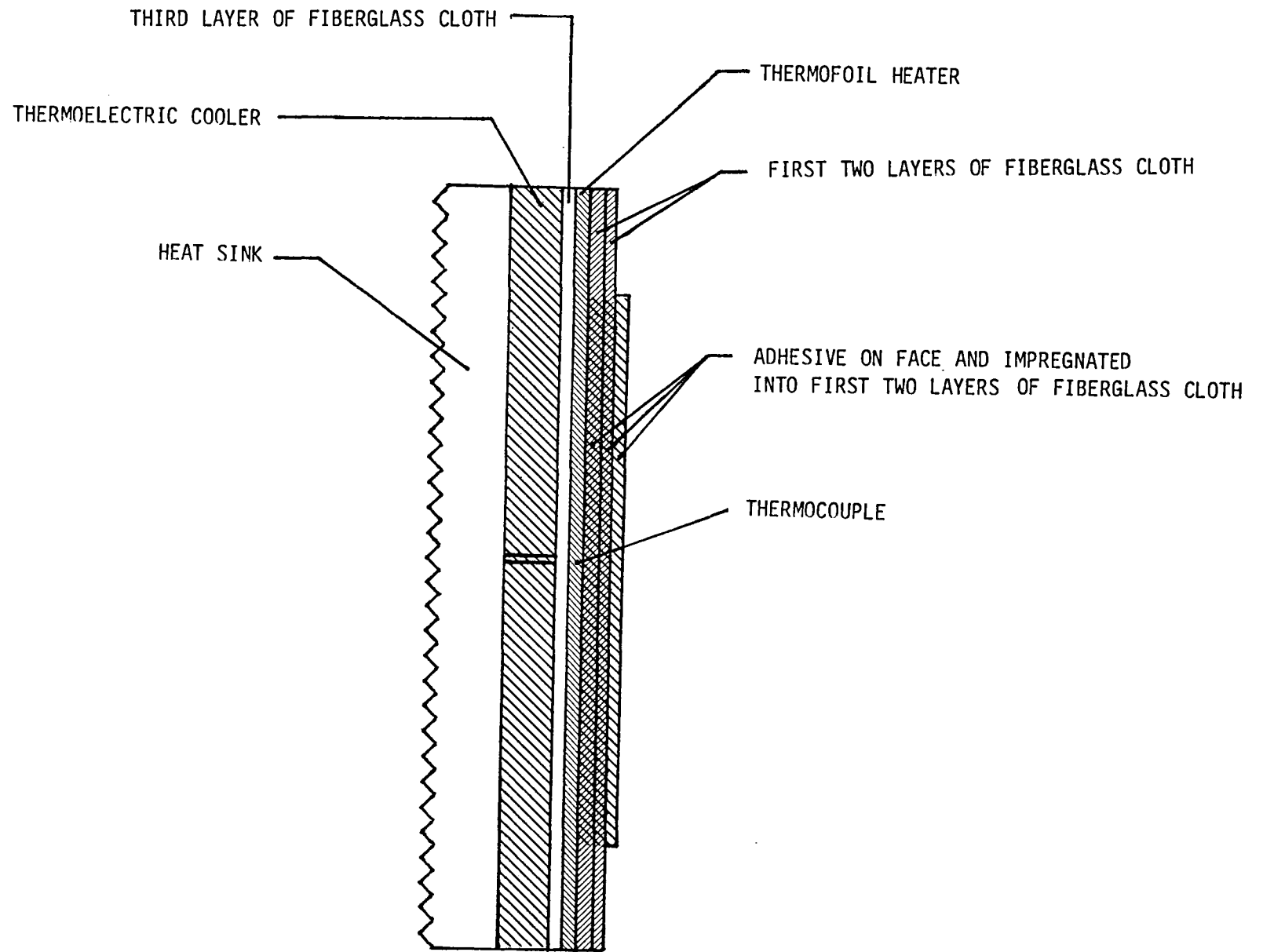
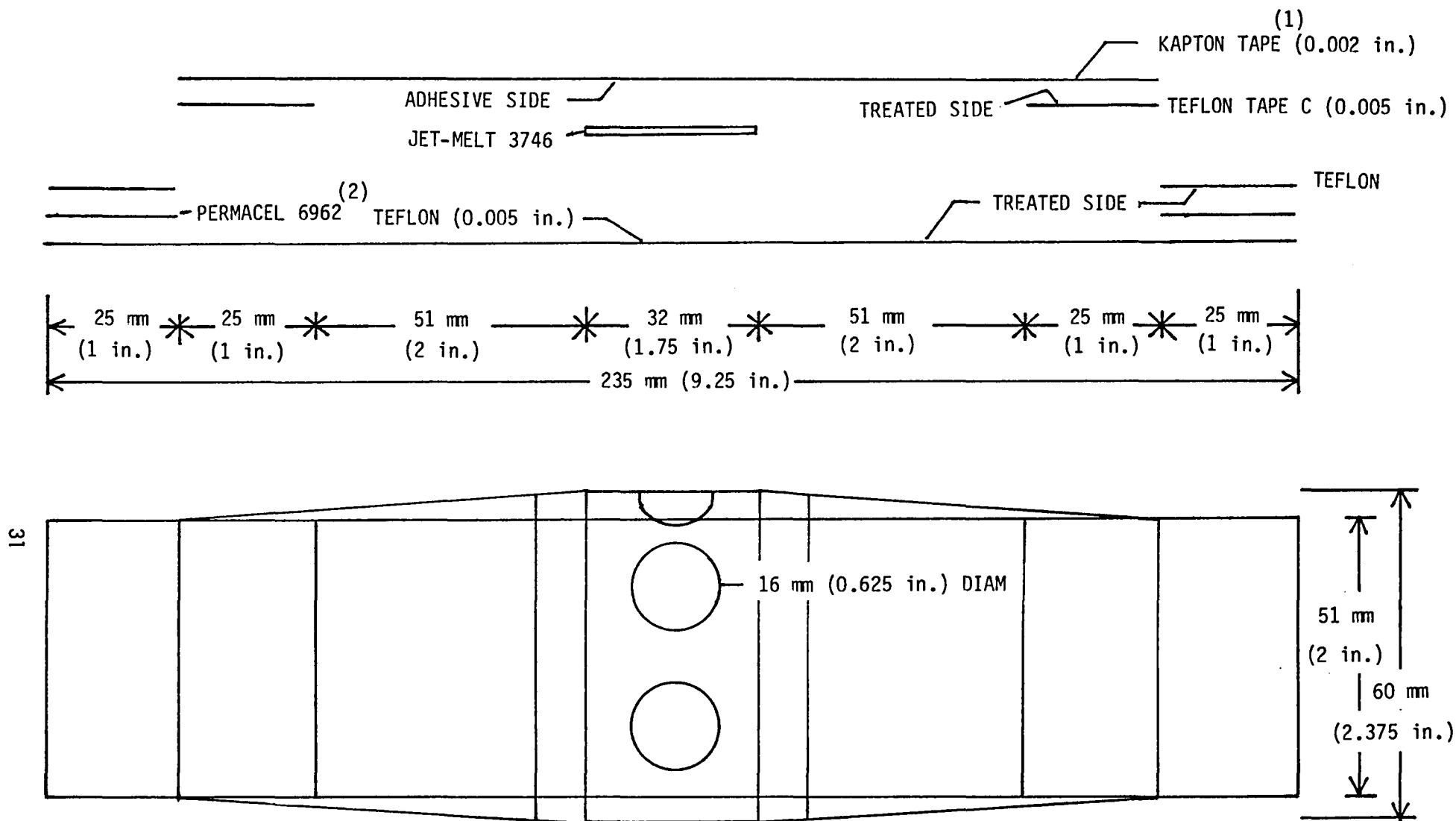


Figure 5. Sketch of a cross section of a single adhesive pad.



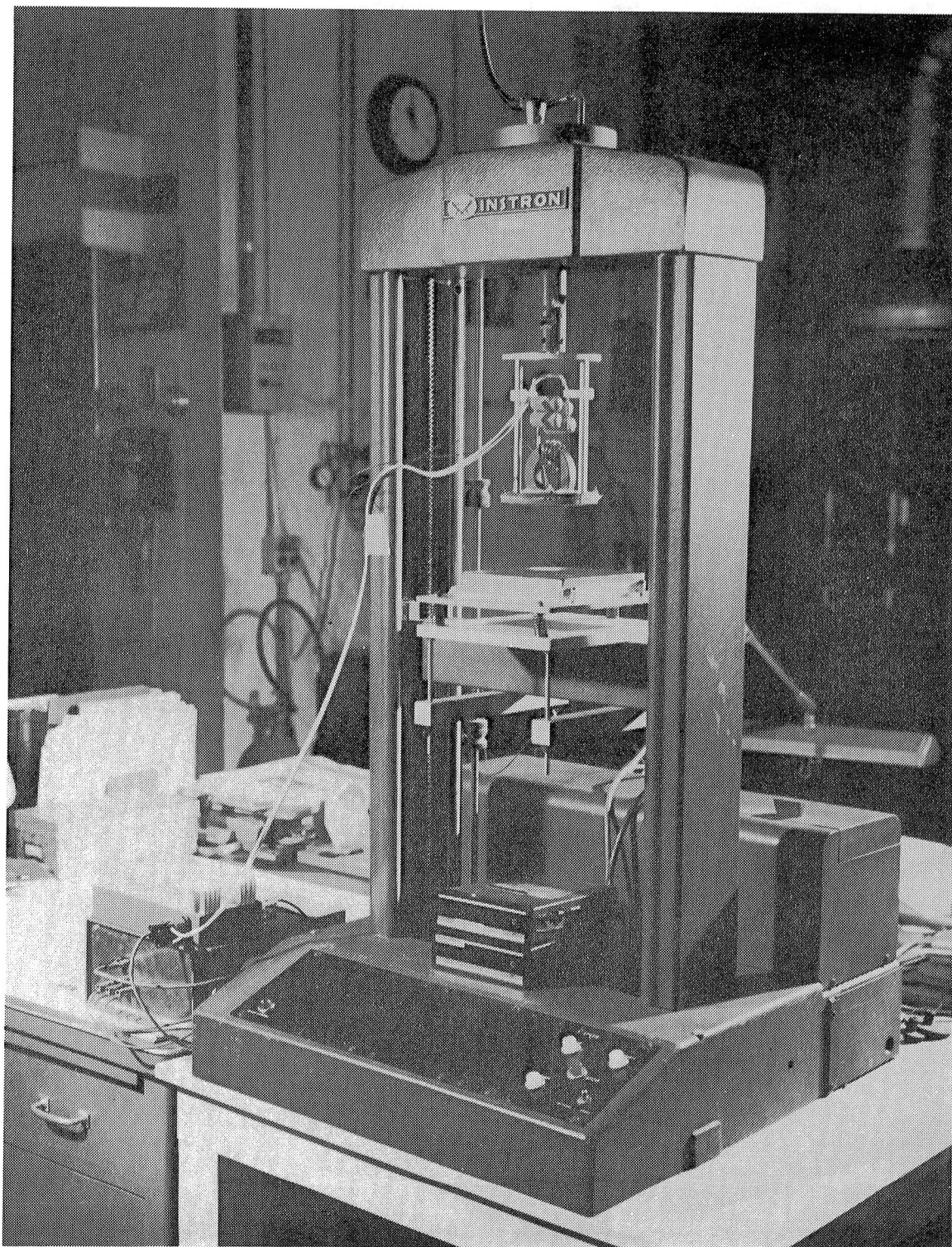
- (1) KAPTON TAPE - DODGE FLUOROGLAS DIV. NO. 2345-2
- (2) PERMACEL EE-6962 DOUBLE FACED KAPTON FILM ELECTRICAL TAPE, 0.001 in. KAPTON BACKING

Figure 6. Diagram of hot melt recharge.

## RECHARGE PROCEDURE

1. POSITION SAA PADS FOR BEST ACCESS AND VIEWING.
2. GRIP THE TAPE BY HOLDING THE TWO TABS ON THE SAME END OF THE TAPE, REMOVE THE PROTECTIVE TEFLON FILM (CLEAR) AND DISPOSE. THIS LEAVES THE PRESSURE-SENSITIVE TAPE (KAPTON TAPE) WITH THE HOT MELT FILM CHARGE.
3. POSITION THE HOT MELT CHARGE OVER THE THERMOFOIL HEATER AREA, PRESS THE KAPTON TAPE ON THE PERIPHERY OF THE PAD AND AGAINST THE FIBERGLASS CLOTH TO HOLD THE CHARGE IN CONTACT WITH THE THERMOFOIL HEATER AREA.
4. TURN HEATER SWITCH ON; WHEN MELT TEMPERATURE IS REACHED (INDICATED BY RED INDICATOR LIGHTS CYCLING), TURN HEATER SWITCH OFF AND TURN COOLER SWITCH ON, COOL TO ABOUT 65°C (150°F), TURN COOLER SWITCH OFF.
5. REMOVE KAPTON TAPE FROM PAD, LEAVING THE HOT MELT CHARGE IN PLACE ON THE THERMOFOIL HEATER AREA.

Figure 7. - Hot melt film recharge procedure.



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Figure 8. Toroid gun technique for heating hot melt adhesive.



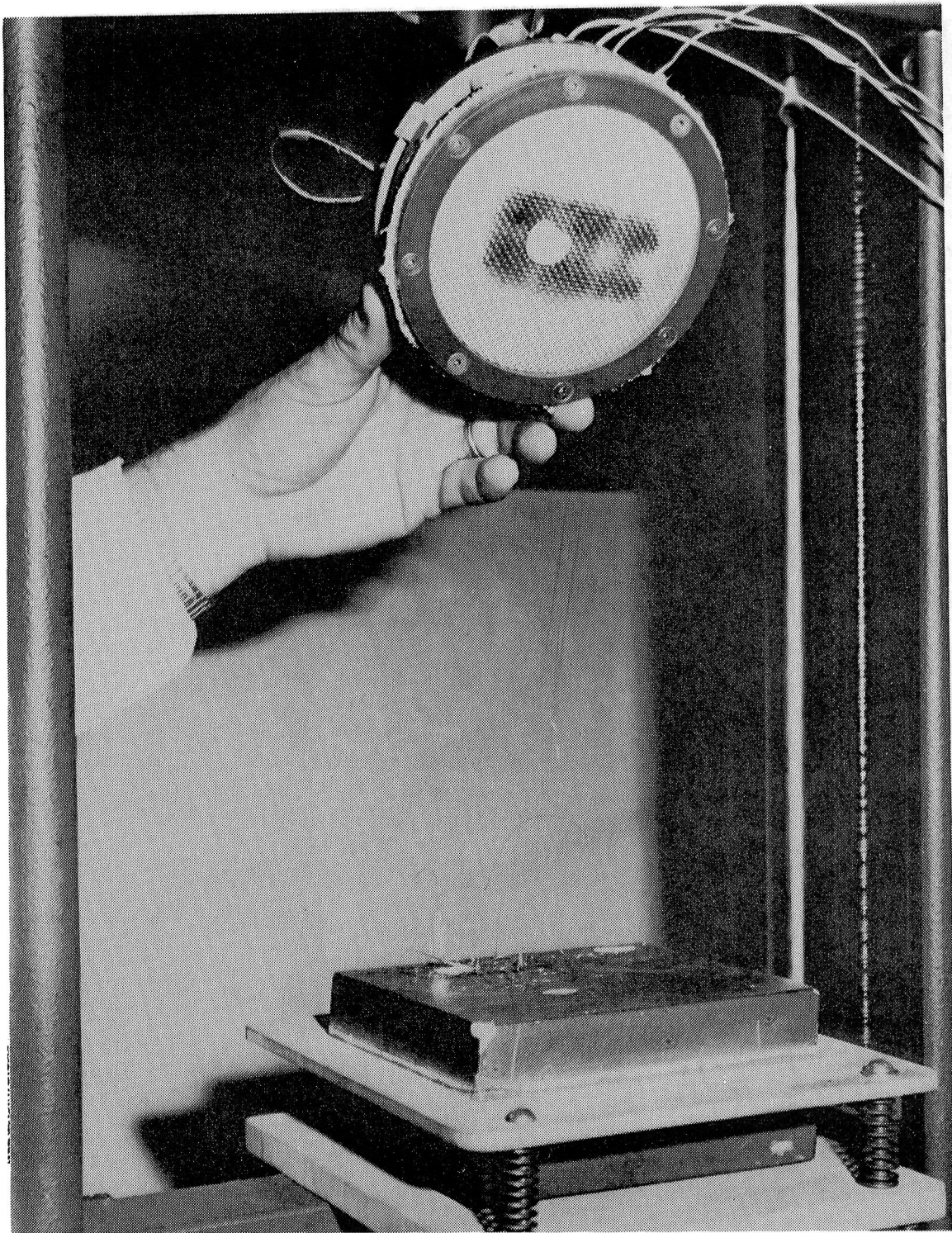


Figure 9. Single pad using thermofoil heater technique for heating hot melt.



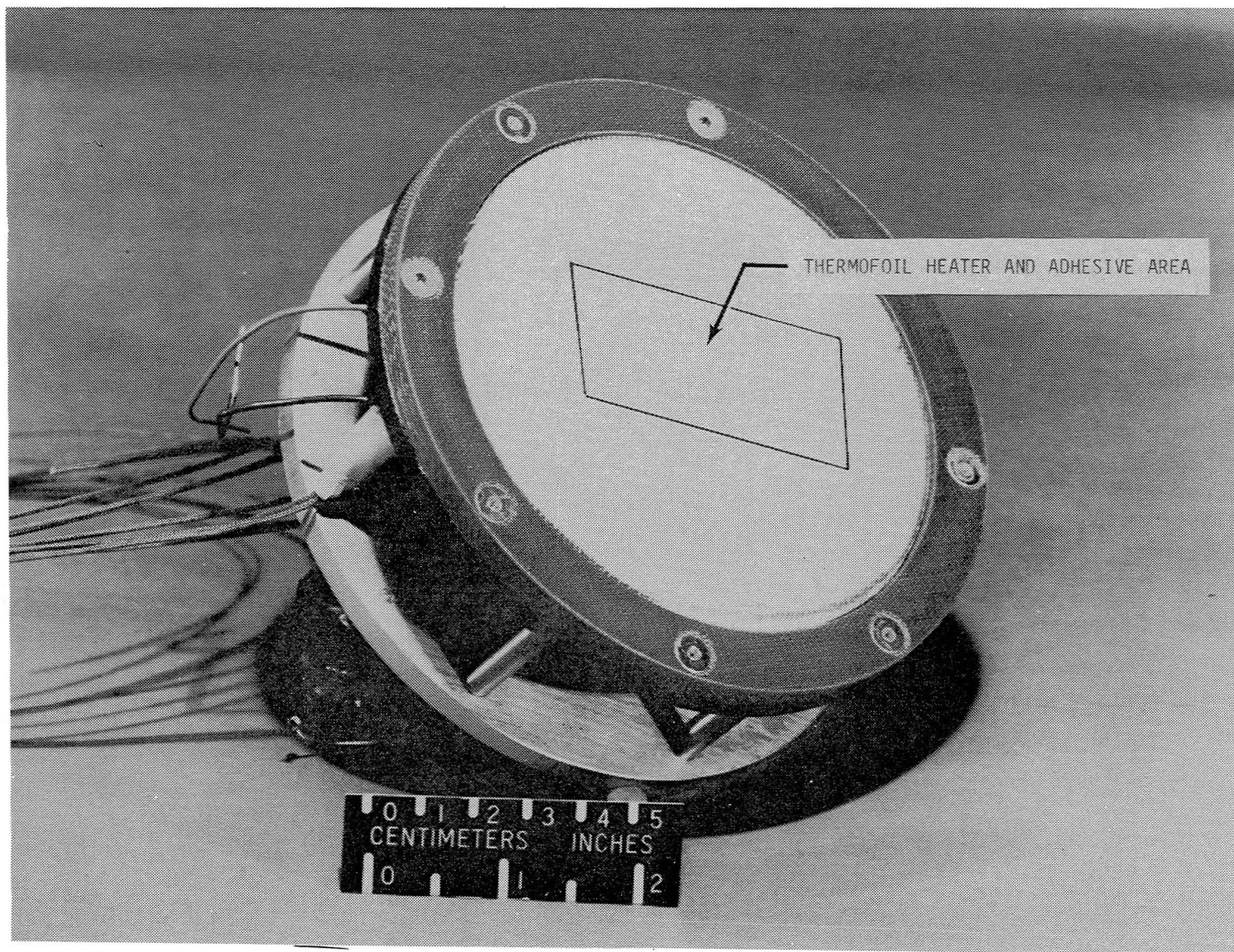


Figure 1. Photograph of a single pad unit.

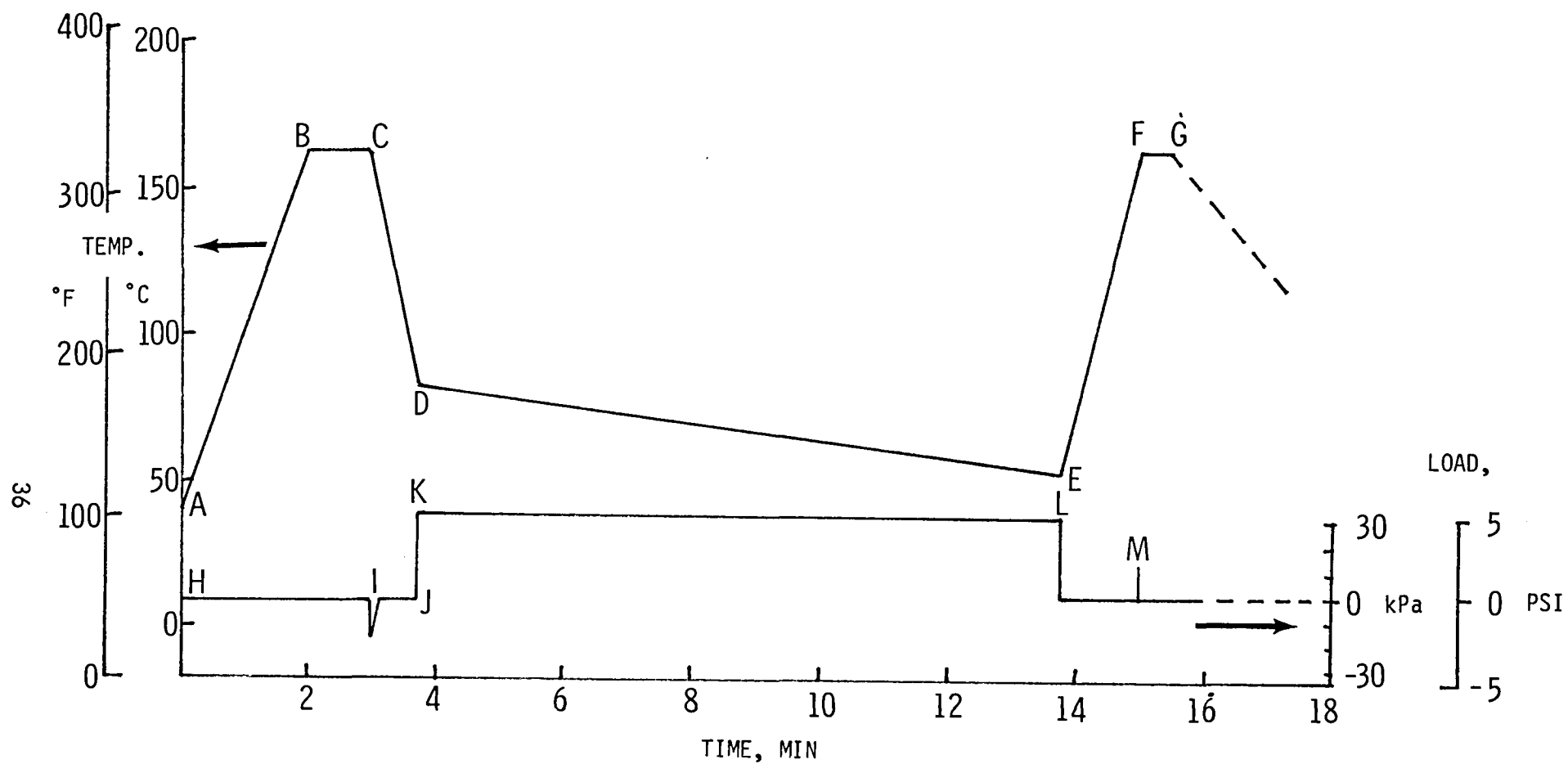


Figure 11. Temperature and load time histories for single pad.  
(Nomenclature defined in Figure 12)

## TEST PROCEDURE FOR SINGLE PAD

- A START, ROOM TEMPERATURE
- A-B HEAT TO 163°C (325°F)
- B-C HOLD 1 MIN
- C CONTACT TILE, 14 kPa (2 PSI) COMPRESSION LOAD, TURN OFF HEATER, START COOLING
- C-D COOL FOR 45 SEC [TEMP. 82°C (180°F)]
- D APPLY 34 kPa (5 PSI) TENSION LOAD
- D-F HOLD LOAD FOR 10 MIN
- E-F HEAT TO 163°C (325°F)
- F START SEPARATION AT 51 CM/MIN (20 IN./MIN)
- G TURN OFF HEATER
- H START, NO LOAD, PARTS SEPARATED
- I APPLY 14 kPa (2 PSI) CONTACT PRESSURE AND RETURN TO NO LOAD
- J APPLY 34 kPa (5 PSI) TENSION LOAD
- K-L HOLD 34 kPa (5 PSI) TENSION LOAD (10 MIN)
- L NO LOAD
- M AVERAGE OF TENSION LOADS OBTAINED DURING SEPARATION (5 "STICKS")

Figure 12. Procedure for single pad stick tests. (Also see Figure 11)

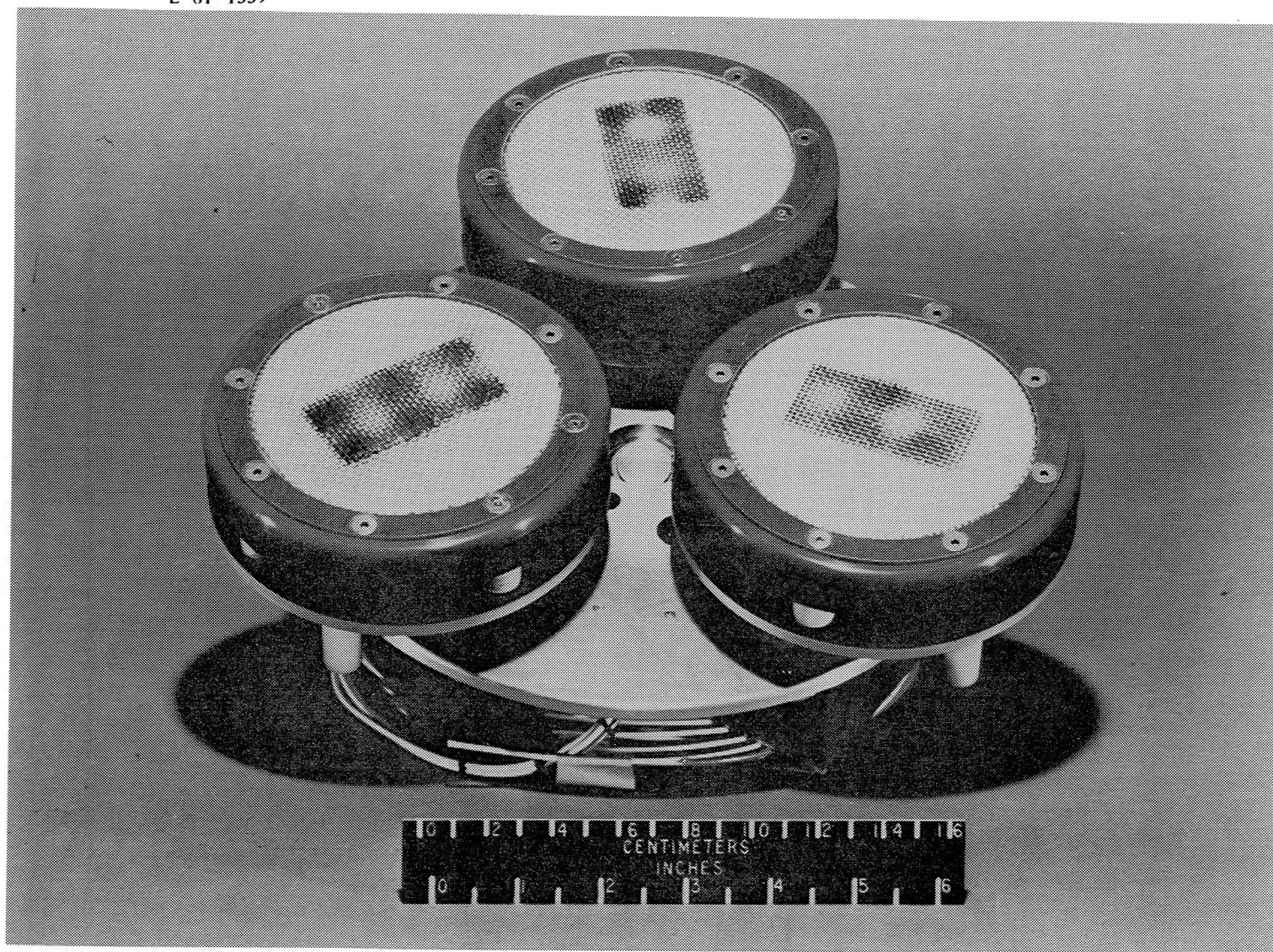


Figure 13. 3-pad engineering development SAA.

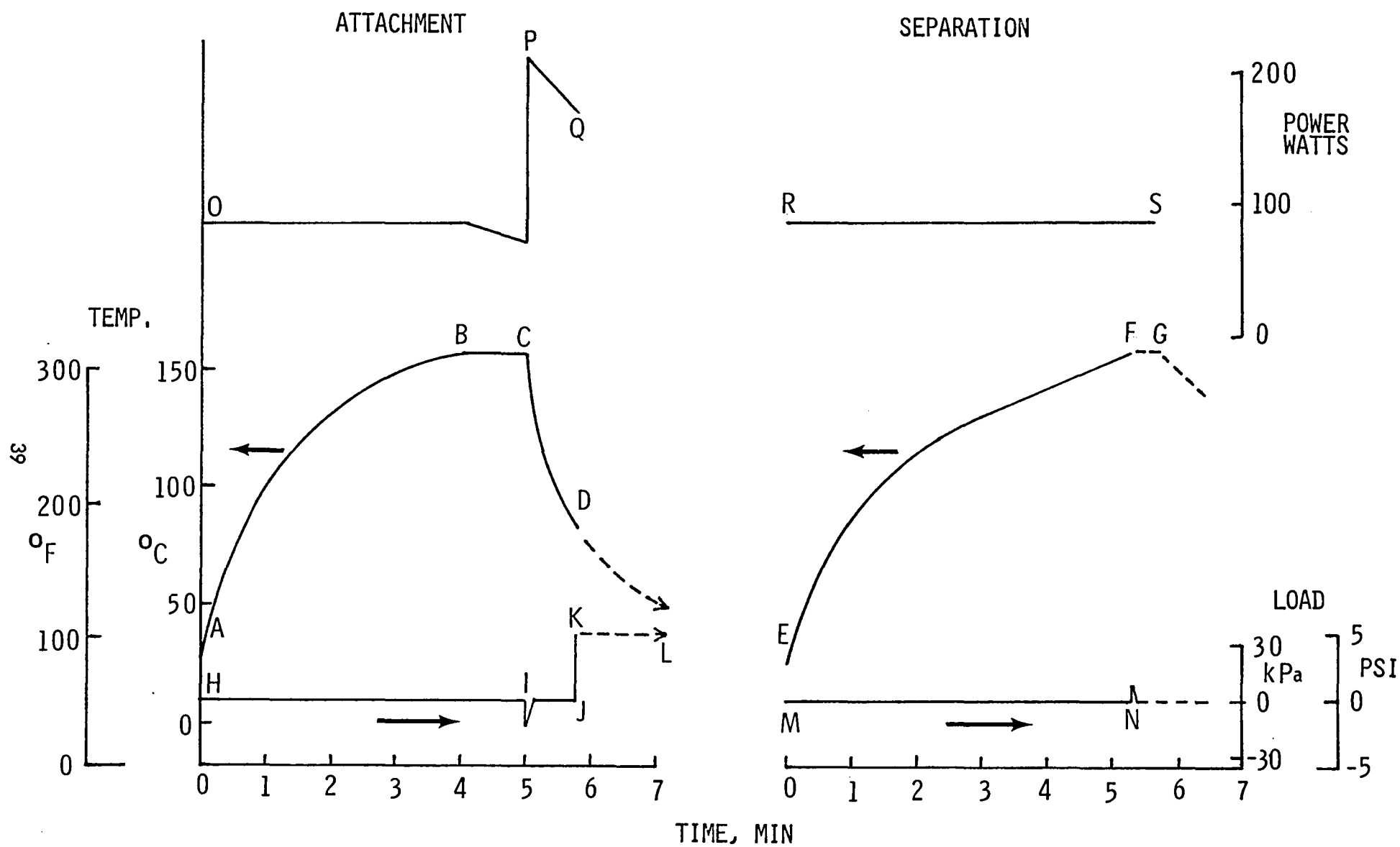


Figure 14. Temperature, power, and load time histories for 3-pad SAA.  
(Nomenclature defined in Figure 16)

A START, RT  
 A-B HEAT TO 163°C (325°F) (TIME TO HEAT ~ 4 MIN)  
 B-C HOLD 1 MIN AT 163°C (325°F)  
 C CONTACT TILES, 14 kPa (2 PSI) COMPRESSION LOAD, TURN OFF HEATER, START COOLING  
 C-D COOL FOR APPROX. 50 SEC [OR TO 82°C (180°F)] TURN OFF COOLER  
 D APPLY 34 kPa (5 PSI) TENSION LOAD [DEAD WT. OF 15.9 kg (35 lb.)]  
 D-E HOLD LOAD FOR ANY PERIOD OF TIME  
 E-F HEAT TO 163°C (325°F) (TIME TO HEAT APPROX. 5 MIN.)  
 F START SEPARATION  
 G TURN OFF HEATER  
 H START, NO LOAD, PARTS SEPARATED  
 I APPLY 14 kPa (2 PSI) CONTACT PRESSURE (AND RETURN TO NO LOAD)  
 J APPLY 34 kPa (5 PSI) TENSION LOAD  
 K-L HOLD 34 kPa (5 PSI) TENSION LOAD  
 M NO LOAD  
 N SEPARATION OF HEAD FROM TILES (USE DEAD WTS.)  
 O POWER TO HEATERS "ON" (FOR HEAT UP)  
 P POWER TO HEATERS "OFF", COOLER POWER "ON"  
 Q COOLER POWER "OFF"  
 R POWER TO HEATERS "ON"  
 S POWER TO HEATERS "OFF"

Figure 15. Procedures for 3-pad SAA tests using dead weights. (Also see Figure 14)

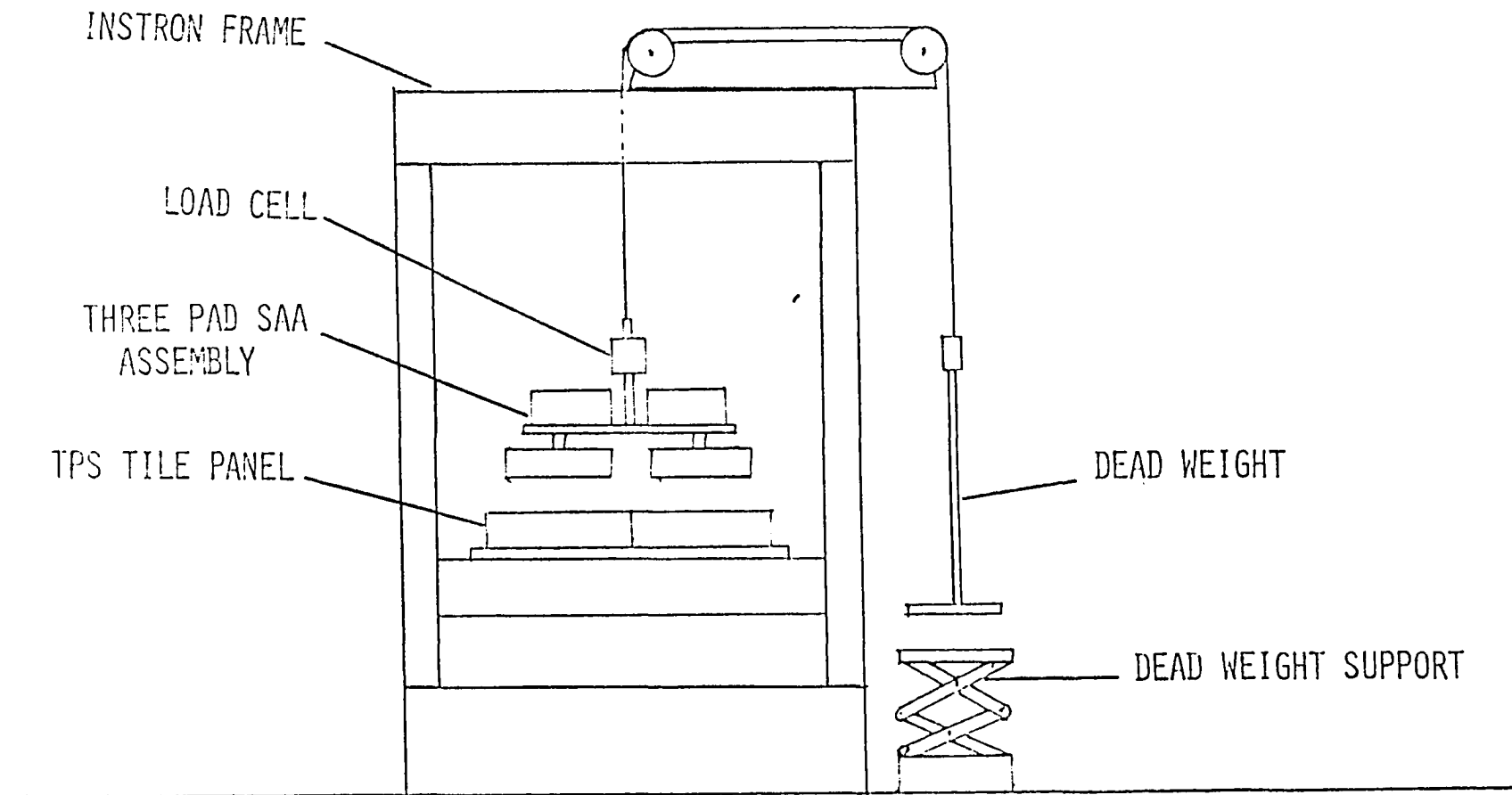


Figure 16. Sketch of dead-weight test equipment for 3-pad SAA.



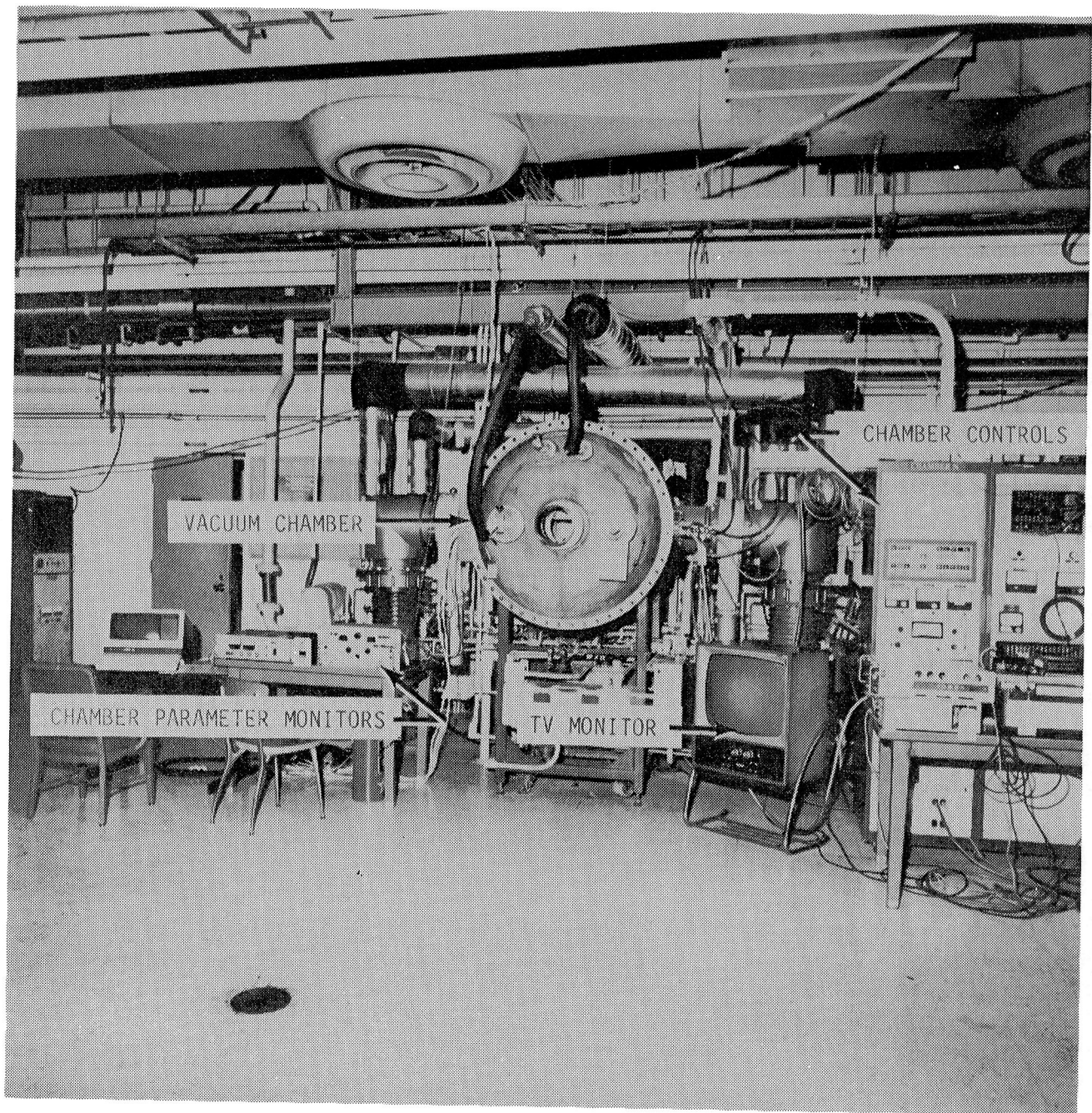


Figure 17. The Johnson Space Center Chamber N facility.



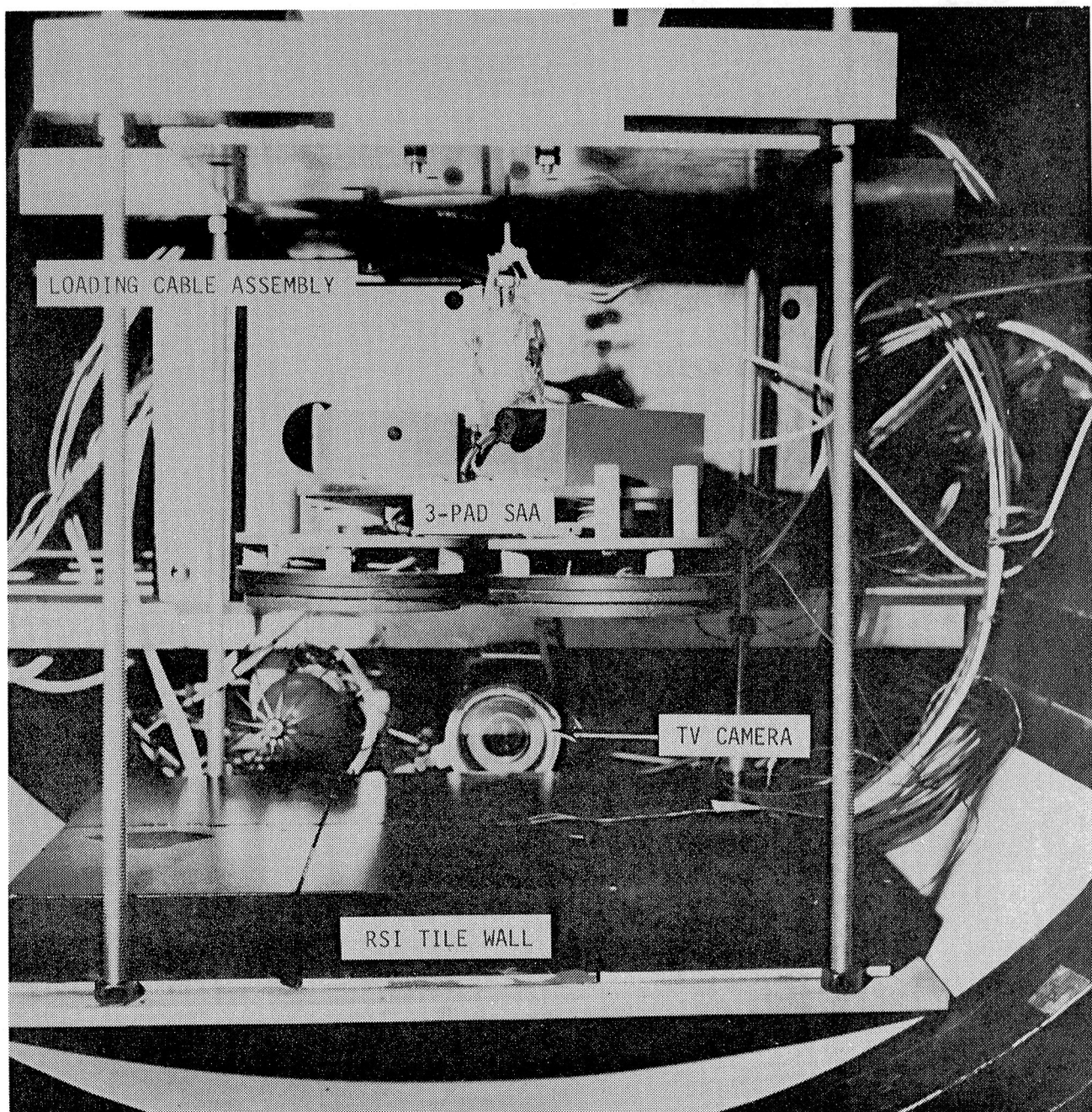


Figure 18. Arrangement of test equipment within Johnson Space Center Chamber N.

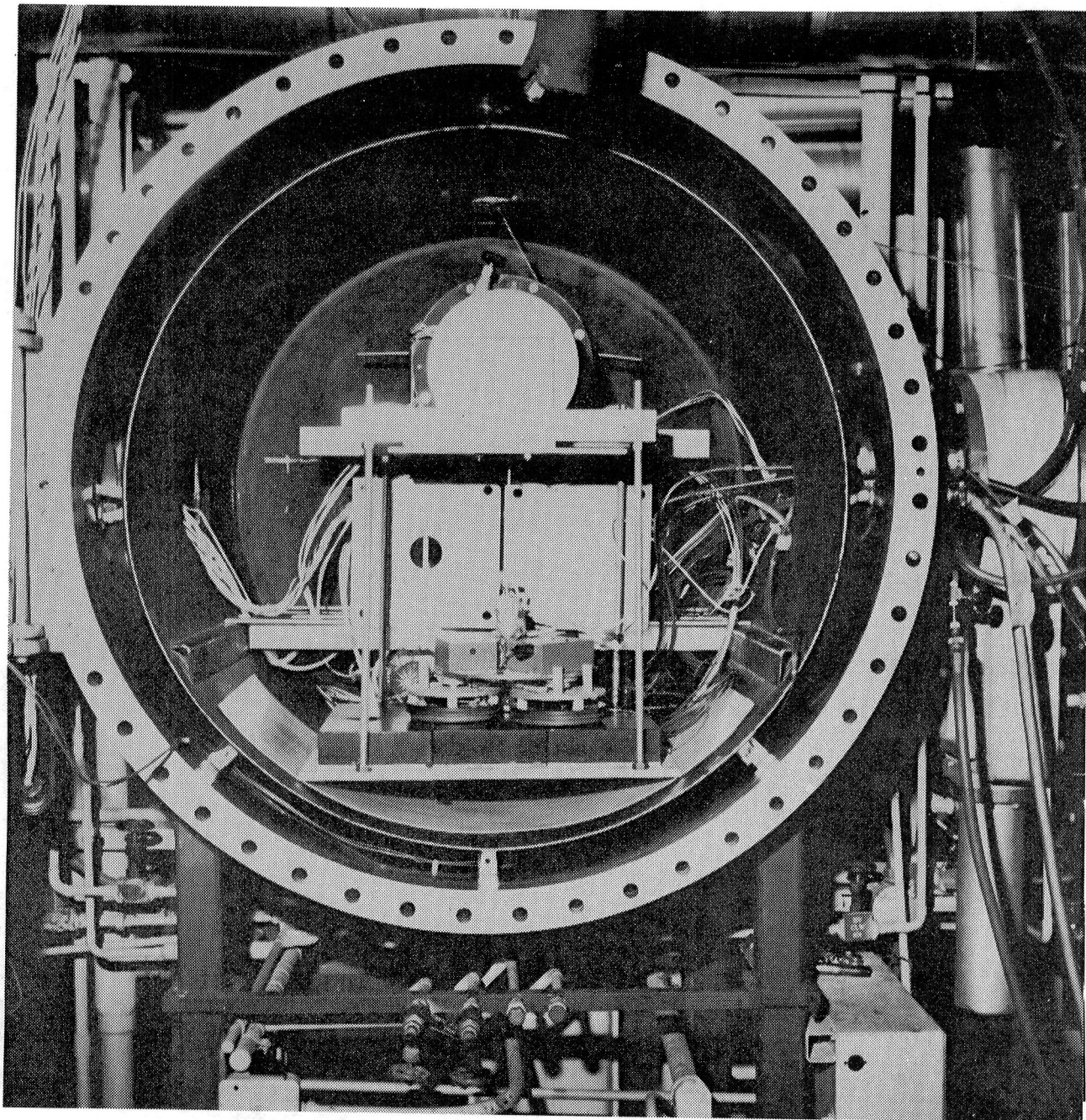


Figure 19. 3-Pad SAA attached to RSI tile wall (under 35 lb load).

APPENDIX A  
MECHANICAL OPERATIONS

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The SAA was fabricated at LaRC with the idea of proving a concept and a prototype model rather than attempting to optimize all facets of the system. Some of the "needs" and "wants" that were considered during the design of the SAA mechanical design were minimal weight, sufficient attachment units to meet tensile and shear force requirements, the ability to adhere to a curved or stepped surface, shock absorber capability, and simple adhesive replenishment. This section of the report gives a parts description with illustrations (Figures A1 through A12) and an assembly description together with illustrative Figures A13 and A14. Photographs of a completely assembled 3-pad SAA with top and bottom views are given in Figures A15 and A16.

## PARTS DESCRIPTION

(See Figures A1 through A12)

- (1) SIDE BUMPER - Molded in air from RTV-560.
- (2) UPPER CLOTH RETAINER - After the three layers of fiber glass cloth are laid together, the upper and lower cloth retainers are fastened to each other by means of #8-32 screws. NOTE: The alignment of the cloth was done at this point. (Material - Bakelite)
- (3) FIBER GLASS CLOTH - 0.016 in. Thickness for each layer. The open mesh allows the adhesive to penetrate the first and second layers of cloth.
- (4) THERMOFOIL HEATER - Located between the second and third layers of glass cloth.
- (5) LOWER CLOTH RETAINER - (Material - Bakelite)
- (6) THERMOELECTRIC COOLERS
- (7) HEAT SINK - The backside of the aluminum heat sink has a diamond knurl face coated with 3M Black Velvet Paint to enhance surface area and radiation of absorbed heat. The thermoelectric coolers are placed on the top of the heat sink with a thermal conductive paste between them and held in place by the retainer clips.
- (8) HEAT SINK RETAINER AND TENSION RING - After the thermoelectric coolers are mounted to the heat sink, the heat sink is aligned with the retainer and the thermofoil heaters in the cloth. With the heat sink in place in the retainer, the tension is applied to the cloth. The tension ring is then fastened with #8-32 screws to the lower cloth retainer. (Material - Bakelite)
- (9) SHOCK ABSORBERS - The polyacrylic rubber shock absorbers have a damping effect when contact with a surface occurs.

- (10) SHOCK ABSORBER PINS - The aluminum pins align the damping material and hold the back absorber plate to the heat sink retainer - tension ring.
- (11) BACK ABSORBER PLATE - The front side of the aluminum absorber plate is coated with 3M Black Velvet Paint to absorb heat radiated from the heat sink during the cool down cycle. The aluminum swivel pin is attached to the back absorber plate by means of #1/4 - 28 socket head cap screw. The thermocouple connector and rotational limit pins are mounted to the back side of this plate.
- (12) ROTATION LIMIT PINS - The pins limit the degree of rotation of the single pads. (Material - Nylon & Mild Steel)
- (13) UNIBAL SWIVEL - The swivel assembly allows approximately 11° of rotation for flat sticks on curved surfaces. The swivels have grease lubrication but can be purchased with a micro-seal lubrication for applications in space. The one large swivel mounted in the center allows 25° of rotation, therefore, allowing 36° total rotation.
- (14) SWIVEL RETAINERS - The aluminum retainers hold the three 0.5 in. I.D. swivels and one 0.75 in. I.D. swivel to the main plate.
- (15) MAIN PLATE - The aluminum main plate holds the electronic control circuits, single heads, etc.

#### ASSEMBLY

(See Figures A13 and A14)

- I. FIBER GLASS CLOTH ASSEMBLY - The first layer of the fiber glass which had been masked off with Kapton tape was impregnated with the Jet-Melt 3746

adhesive. The Kapton tape acts as a border to keep the adhesive from flowing into cold areas away from the film heaters. The film heater was attached to the third layer of glass cloth by means of Kapton tape sewn to the second and third glass cloth layers. The thermocouple (Type "E") was centered between the first and second layers of cloth such that the thermocouple bead was located between elements of the film heater. The first and second layers were aligned one over the other. Power was applied to the film heater. The adhesive which was impregnated in the first layer, melts and wicks into the second layer of glass cloth, incapsulating the thermocouple and fusing the first and second layers of cloth together. The third layer of cloth protects the thermoelectric coolers from heat transfer during the heat-up cycle for attachment or detachment of the pads. A 0.010 in. thick adhesive film was placed over the thermofoil heater area. Power was applied to melt the adhesive film to the surface of the first layer of glass cloth. The purpose of the first layer of cloth was to add to the thermal mass during attachment and to decrease the rate of cool down which could produce a bond failure.

II. RETAINER RING ASSEMBLY - After the adhesive-impregnated glass cloth/thermofoil was assembled, the assembly was placed between the retainer rings (Figure A13).

- (1) The alignment of the adhesive impregnated glass cloth/thermofoil to the retainer ring and thermoelectric cooler was performed at this point. The center lines of both the retainers and the thermofoil heater were made to coincide with the thermoelectric cooler directly beneath.



- (2) A small hole, where the fastening screws pass through to prevent the "runners" from being produced in the glass cloth, was made by separating the weave of the glass cloth.
- (3) Wrinkles were removed from the glass cloth and the glass cloth stretched tightly when the retainer rings were fastened.

### III. TENSION RING ASSEMBLY (Figure A14)

- (1) The thermoelectric coolers were placed in the heat sink with a thin coating of thermal conductive paste between them.
- (2) The heat sink, with thermoelectric coolers held in place by the retainer clips, were aligned with the tension ring.
- (3) Before tightly stretching the glass cloth, the heater wires and thermocouple wires were fed through the heat sink. The tension ring was fastened to the lower glass cloth retainer ring while removing the slack from the wires between the glass cloth and heat sink.

### IV. BACK ABSORBER PLATE ASSEMBLY

- (1) With the three Bakelite rings fastened together, the shock absorbers, shock absorber pins, swivel pin, and back absorber plate were assembled.
- (2) The thermocouple plug was connected on the back side of the absorber plate. Wires were fed through the back plate prior to assembly.

## V. MAIN PLATE ASSEMBLY

Swivel retainers with the swivels were mounted on the main plate and snap rings were used to attach the three pads to the main plate. The individual control box for each pad was mounted on back of the main plate. Wires that were fed through the main plate were fastened to terminal strips on the back of the main plate. The main attachment shaft was fastened with snap rings.

Figures A15 and A16 are photographs of top and bottom view of the completely assembled 3-pad SAA.



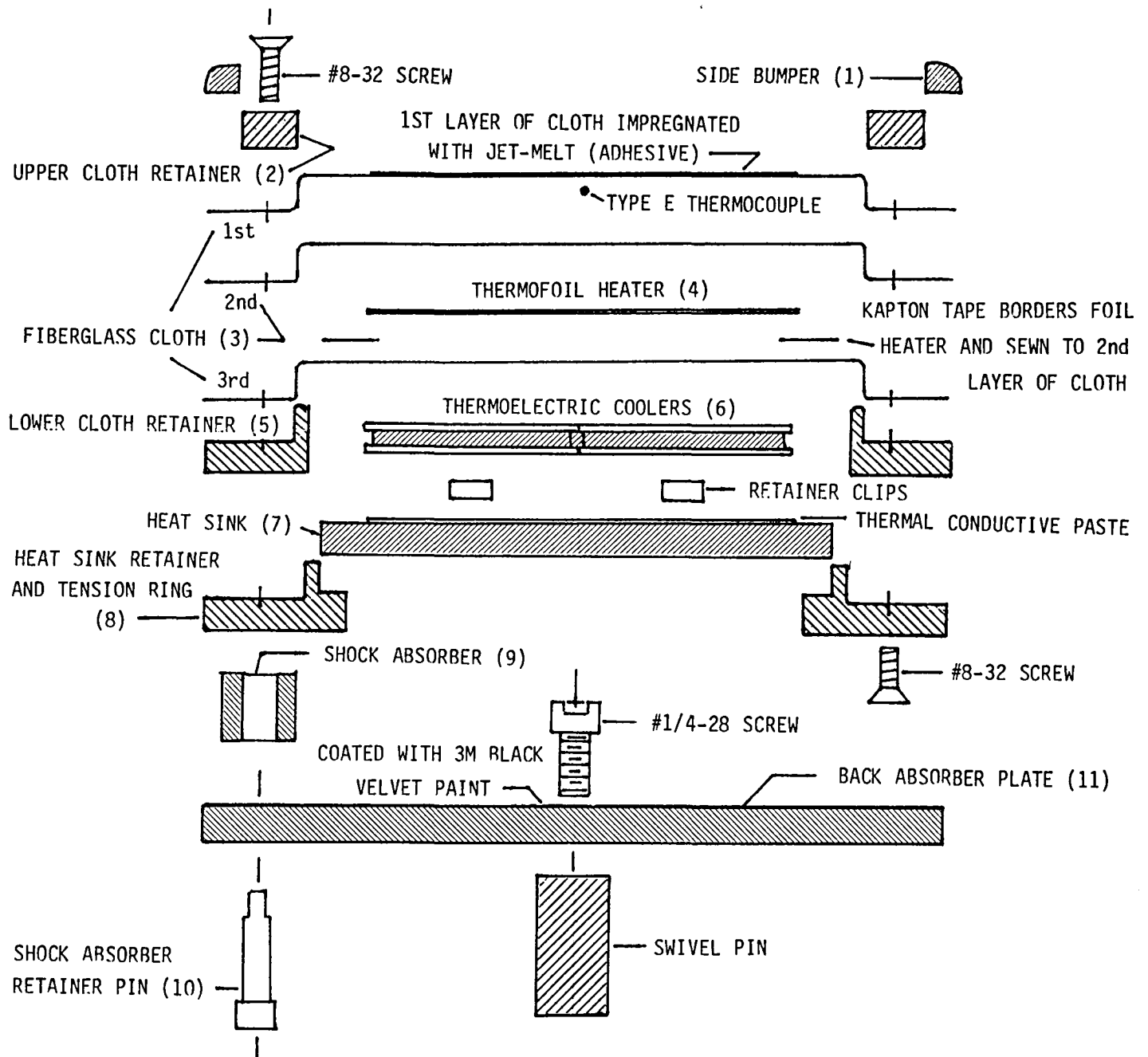


Figure A1. Exploded view of single pad.

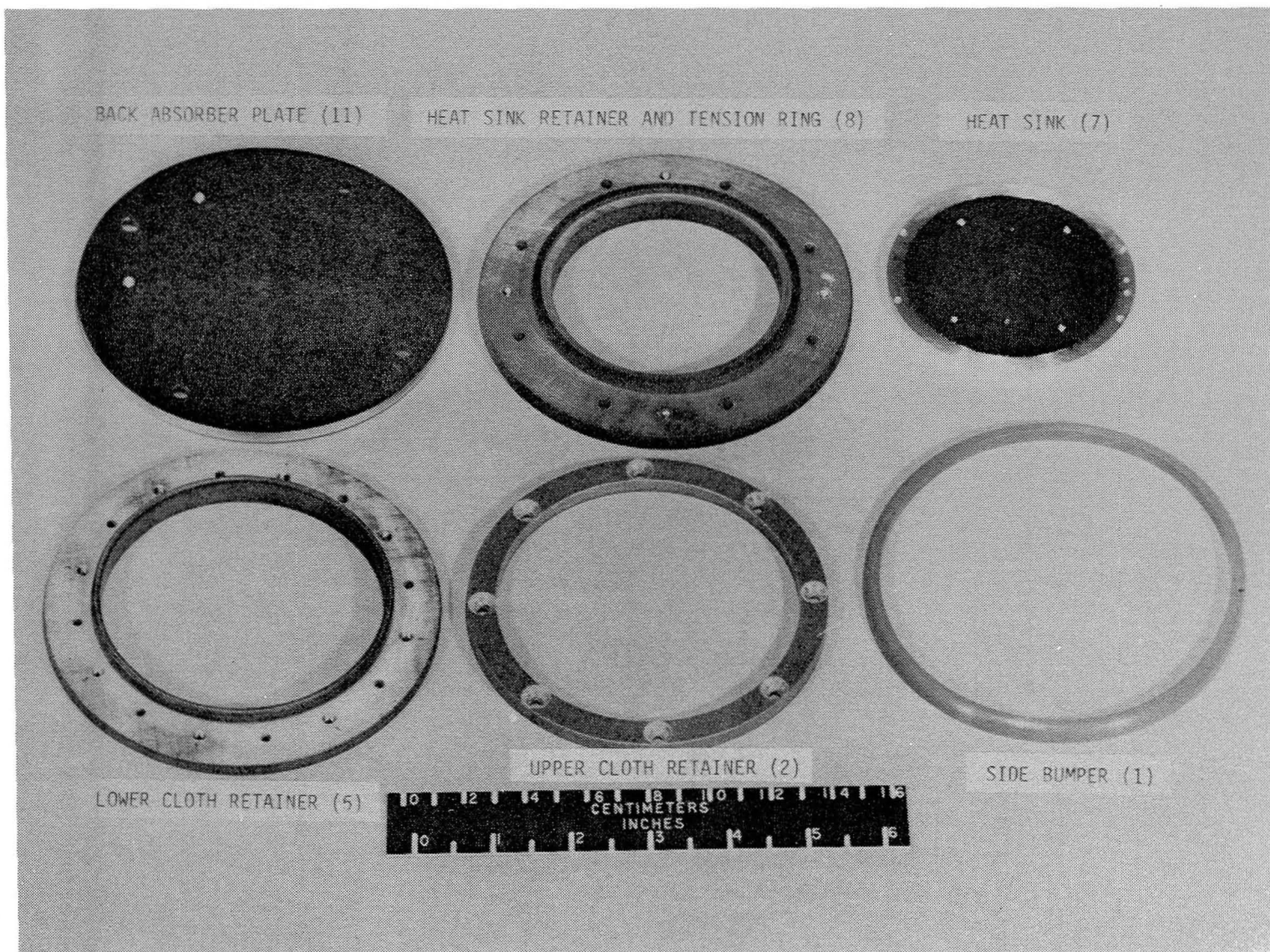


Figure A2. Photograph of several components of single pad.

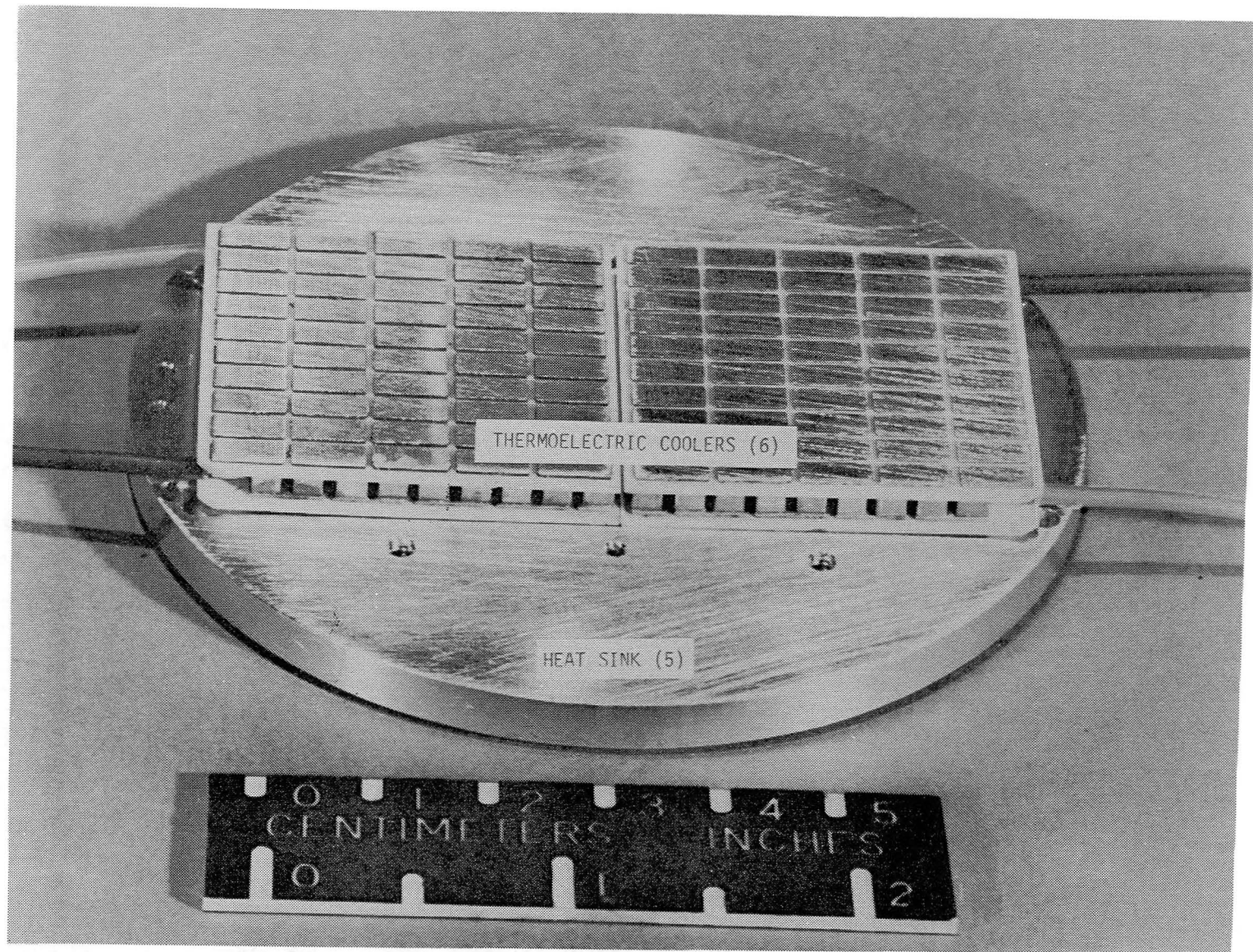


Figure A3. Photograph of heatsink with thermoelectric coolers attached.



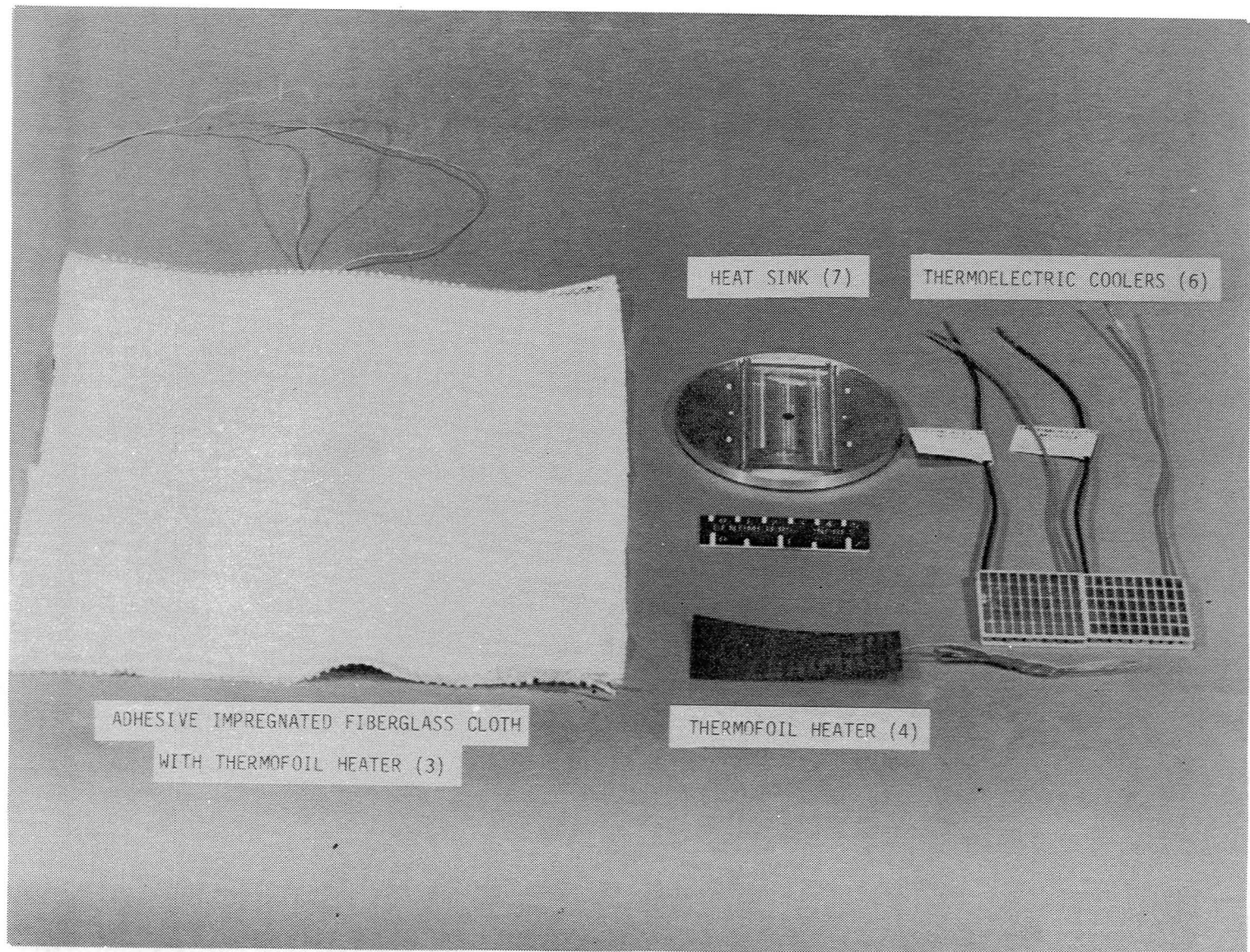
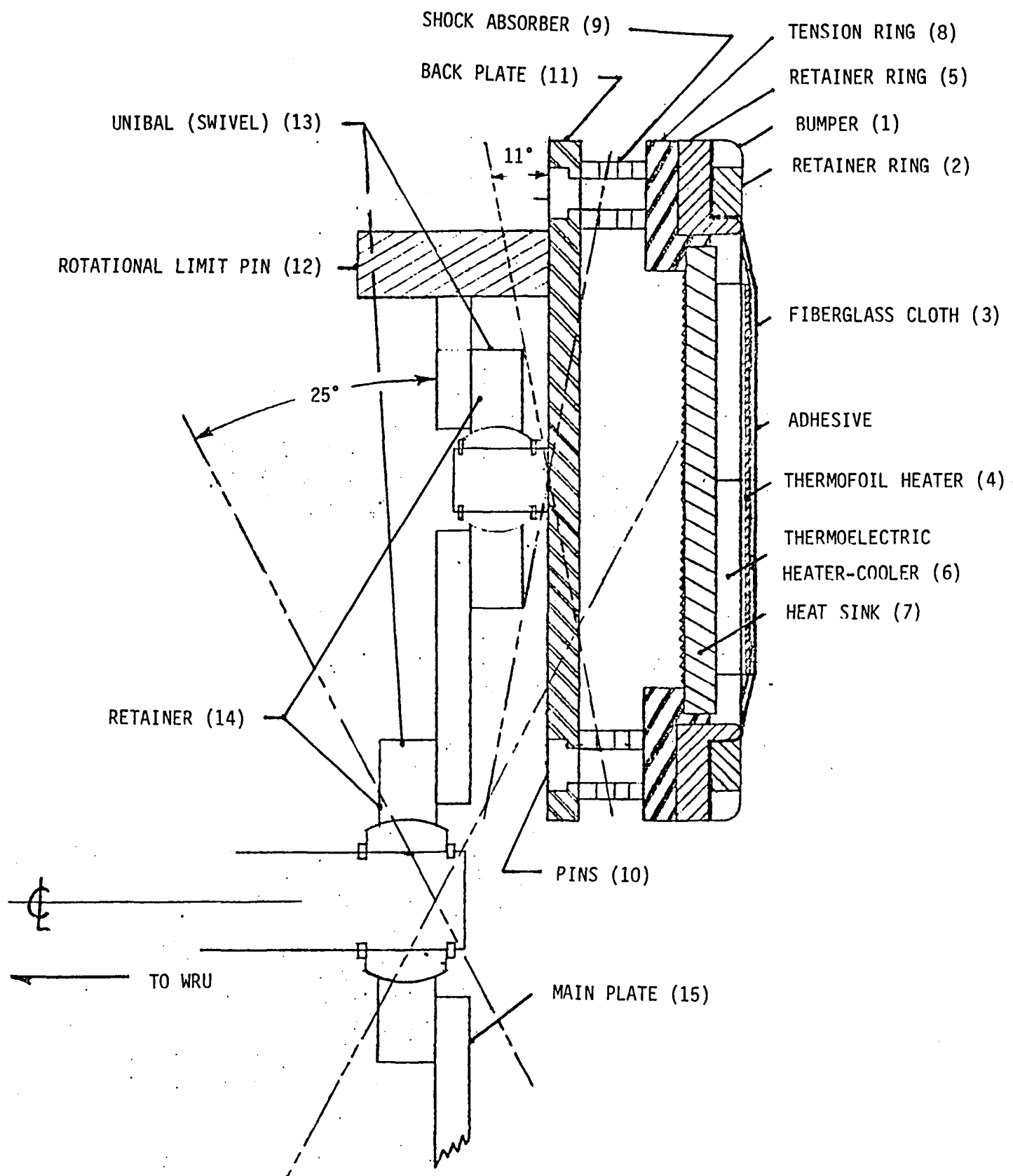


Figure A4. Photograph of several components for single pad.



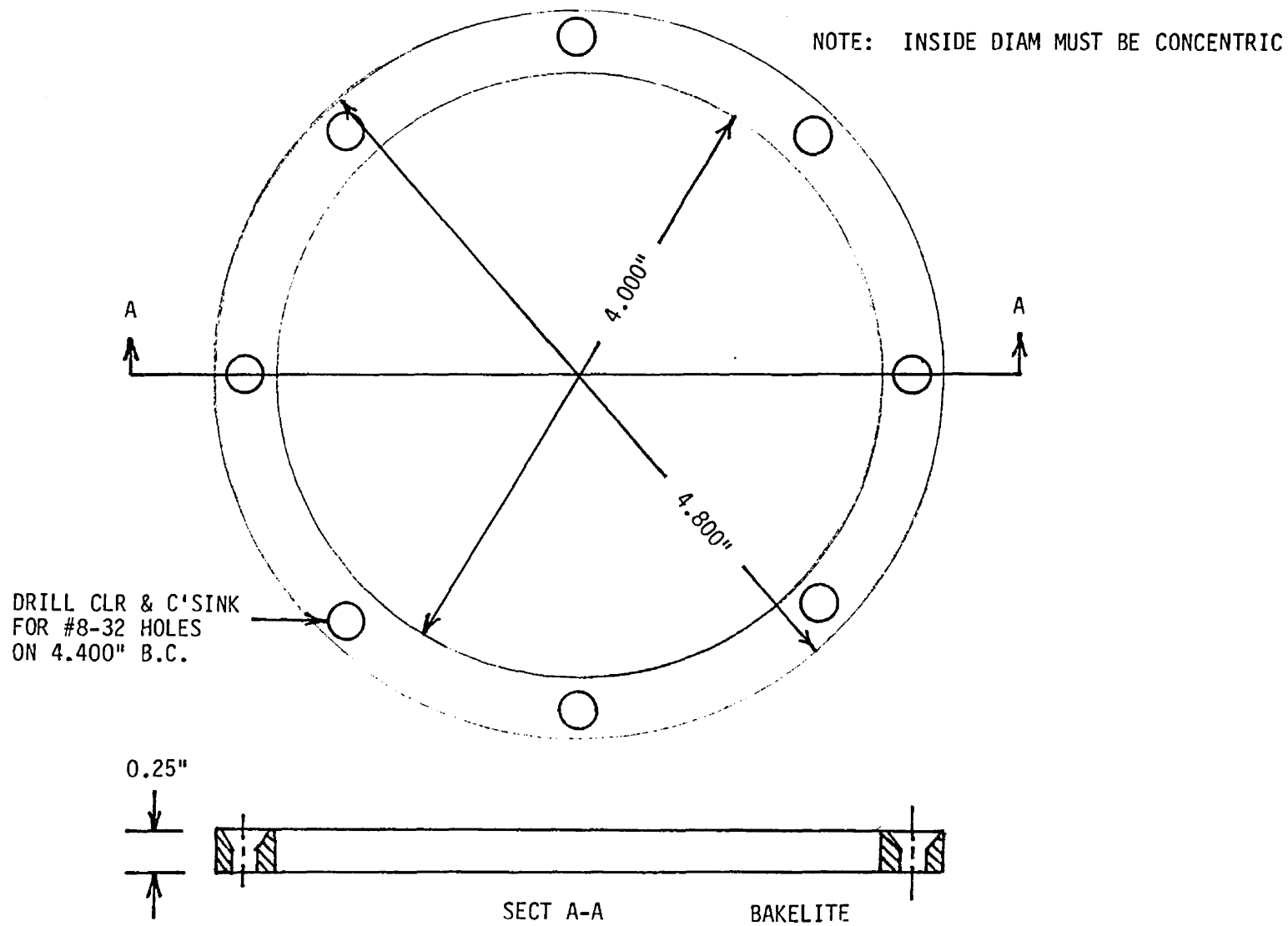


Figure A6. Sketch of upper retainer ring (2).

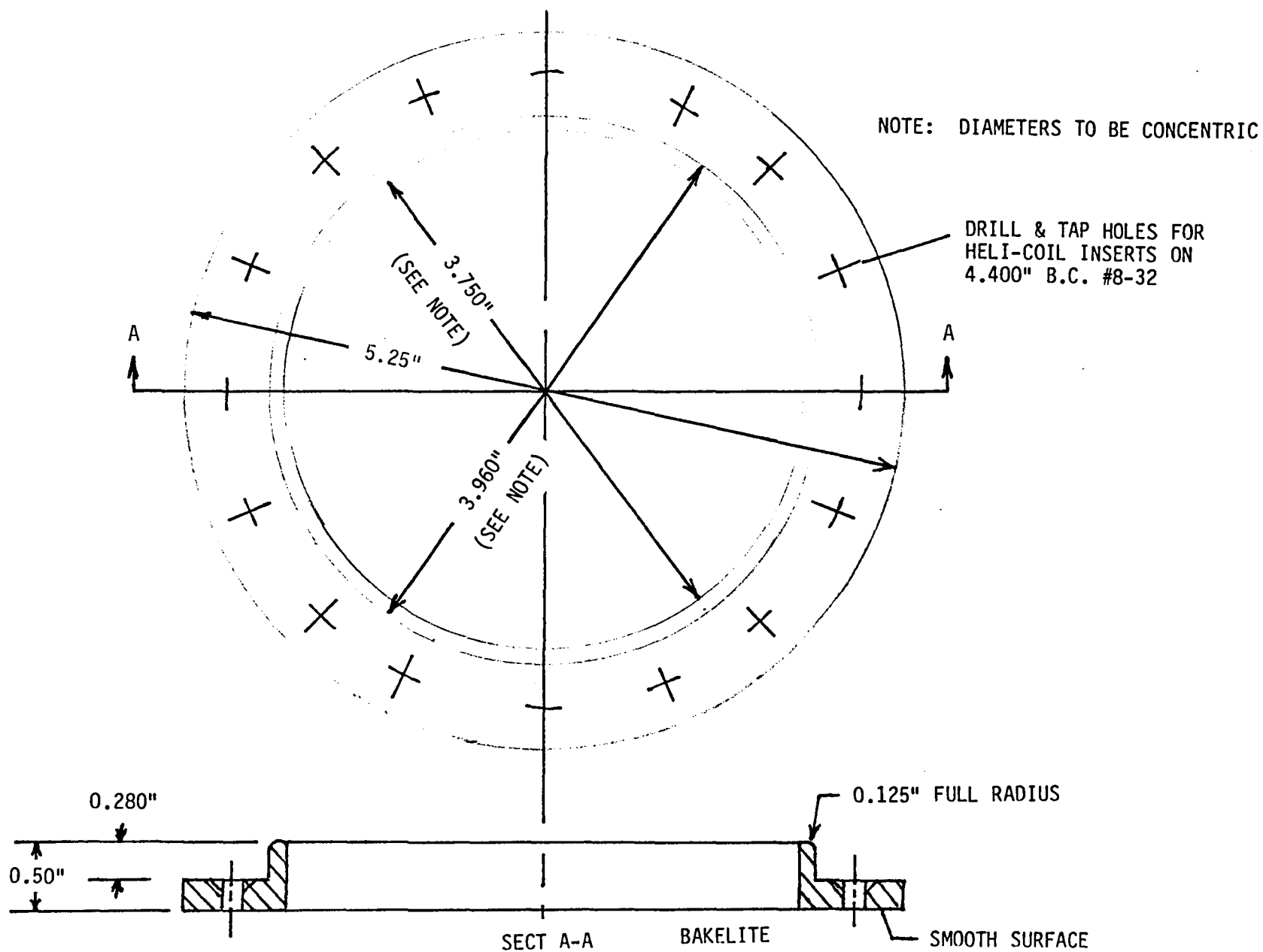
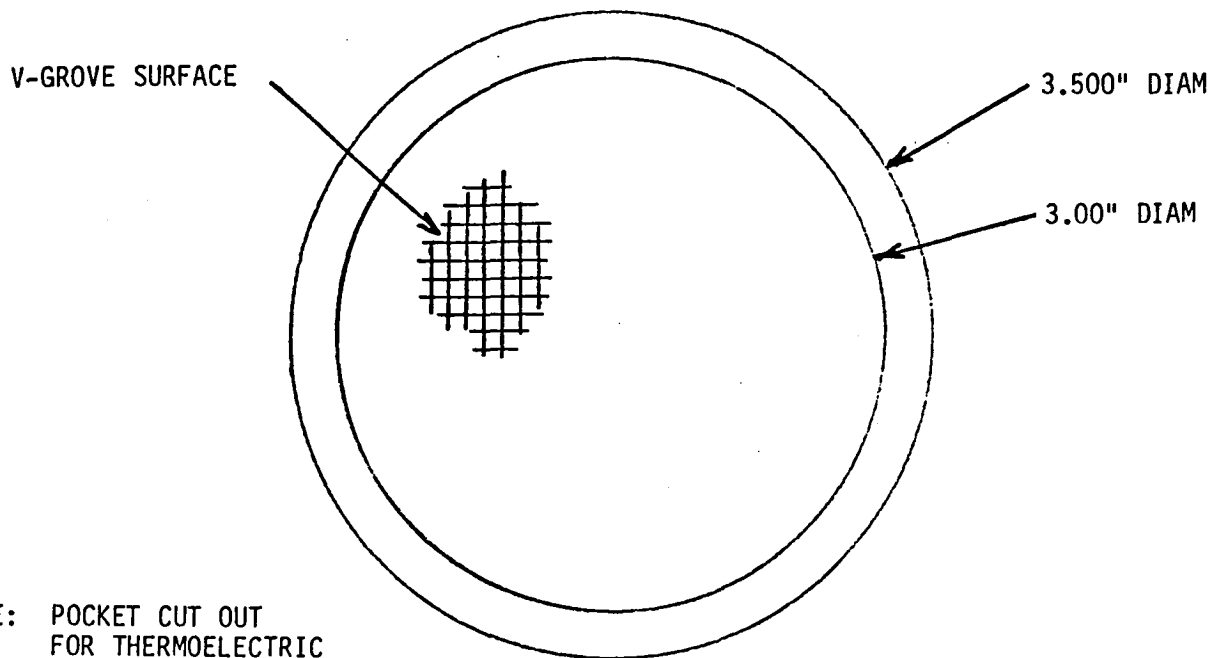
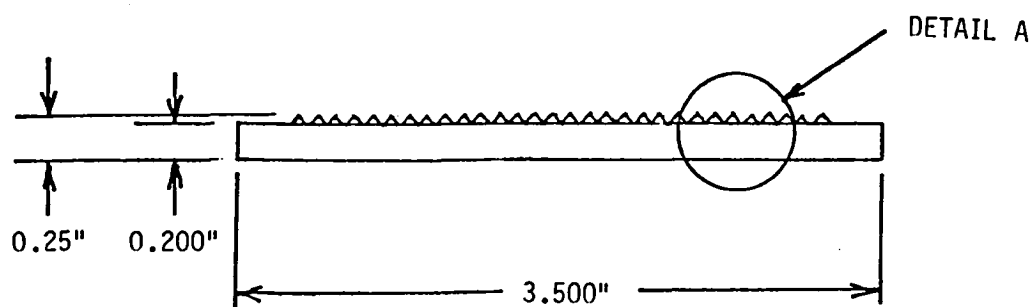


Figure A7. Sketch of lower retainer ring (5).



NOTE: POCKET CUT OUT  
FOR THERMOELECTRIC  
COOLERS AND WIRE FEED  
THRU'S NOT SHOWN



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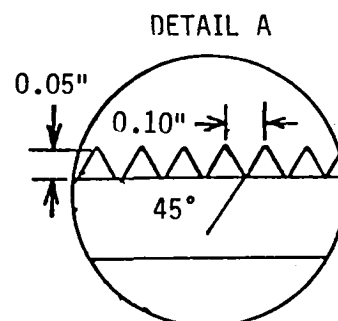


Figure A8. Sketch of heat sink (7).



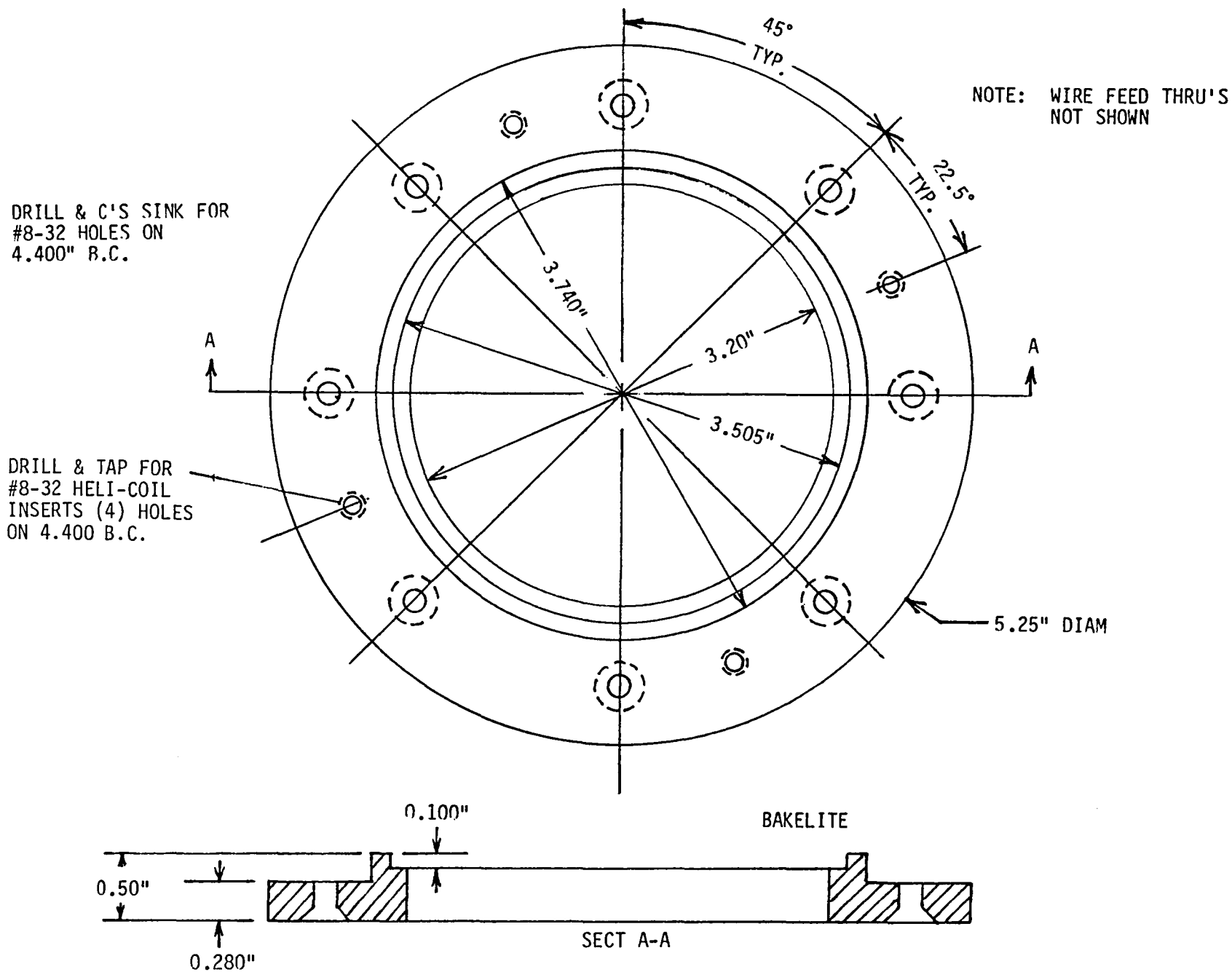
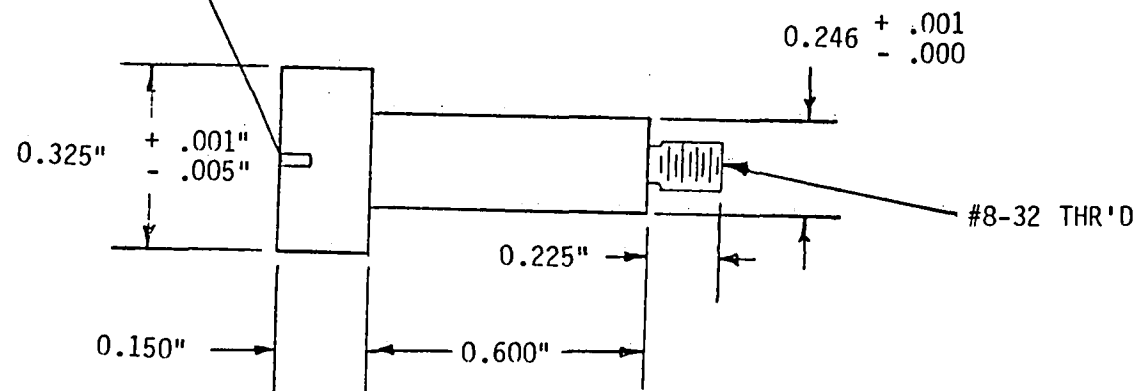


Figure A9. Sketch of heat sink retainer and tension ring (8).

SCREW DRIVER SLOT  
0.0625" x 0.0625" D.P.



2024 ALUMINUM

Figure A10. Sketch of shock absorber retainer pin (10).

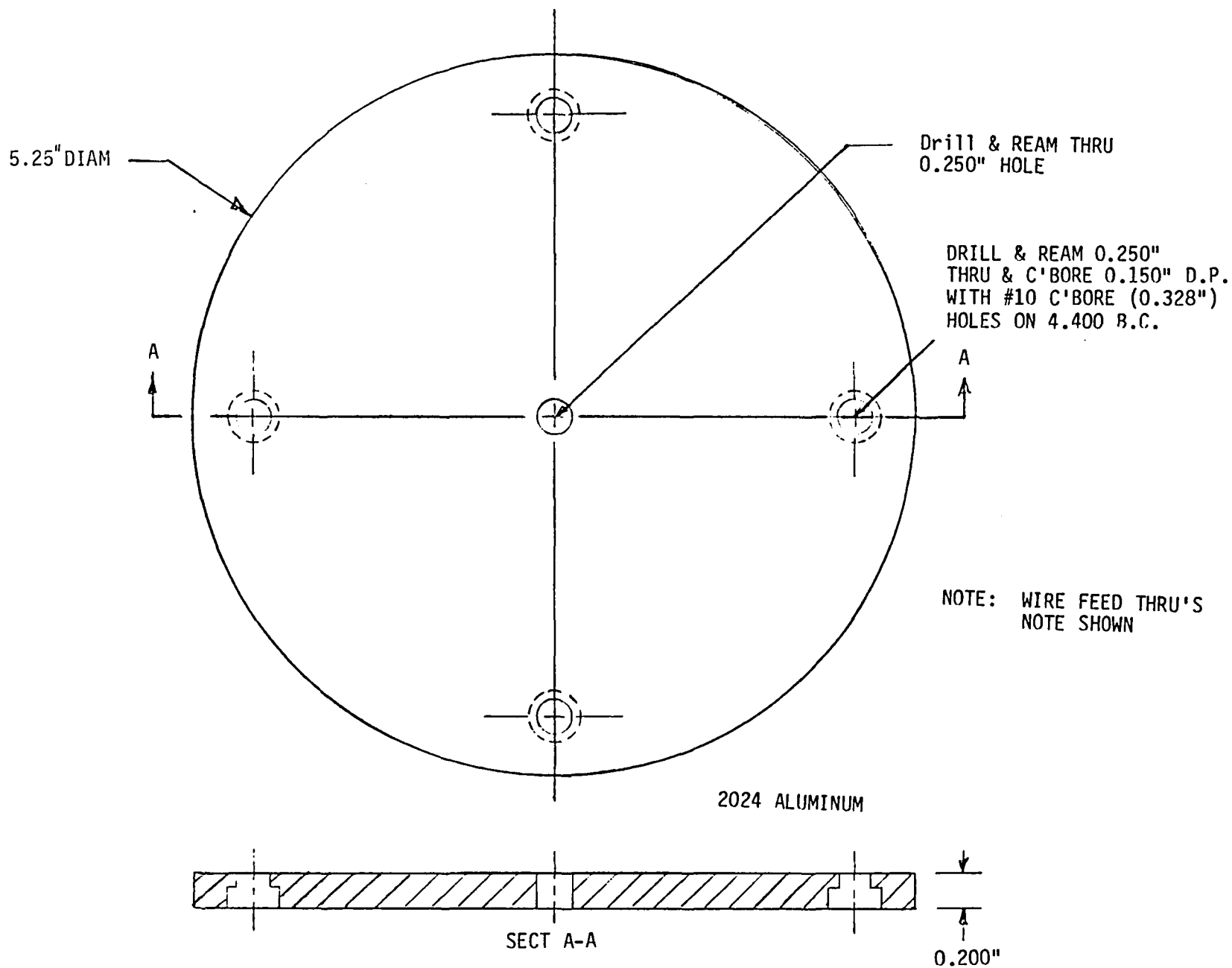
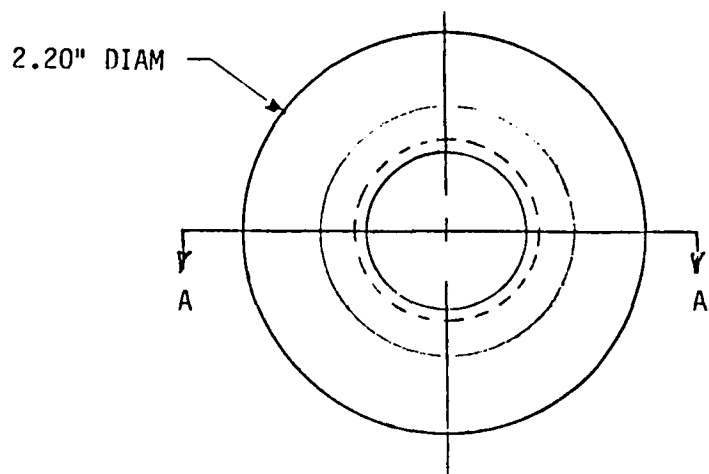
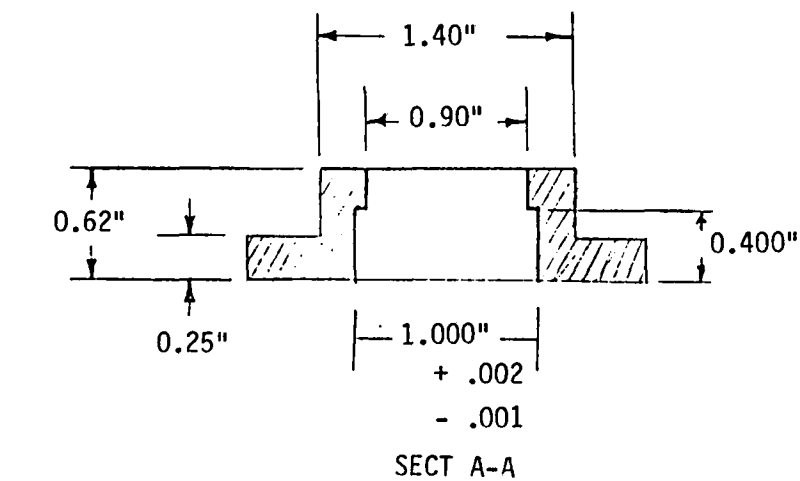
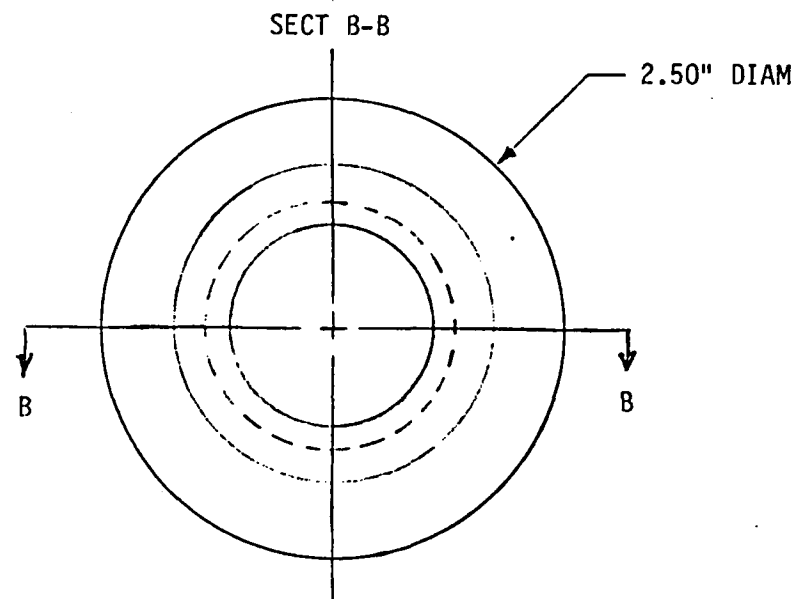
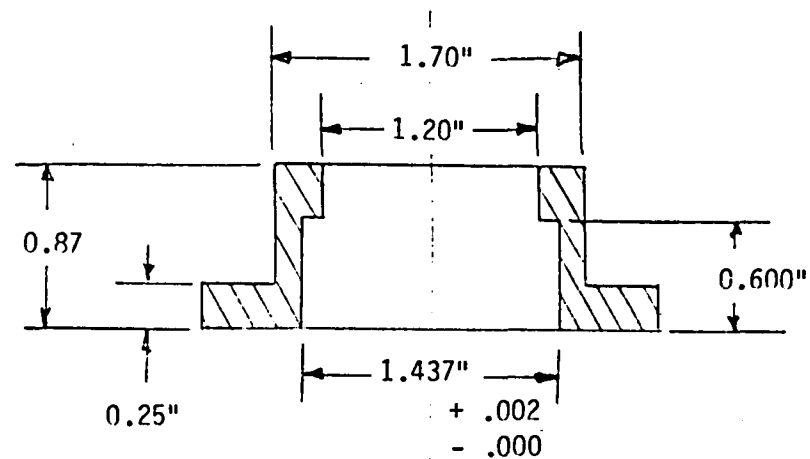


Figure A11. Sketch of back absorber plate (11).



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Figure A12. Sketch of swivel retainers.

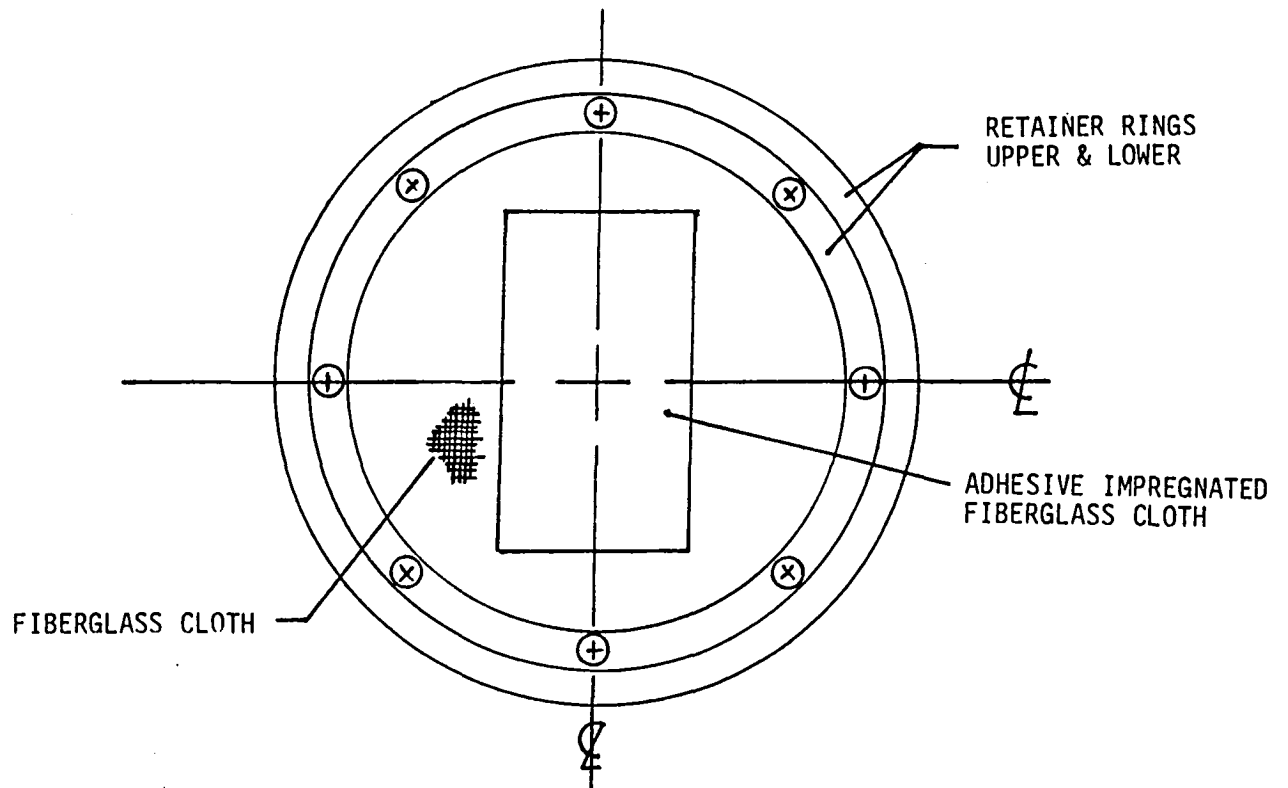


Figure A13. The sketch illustrates the retainer and adhesive impregnated fiberglass cloth/thermofoil alignment.

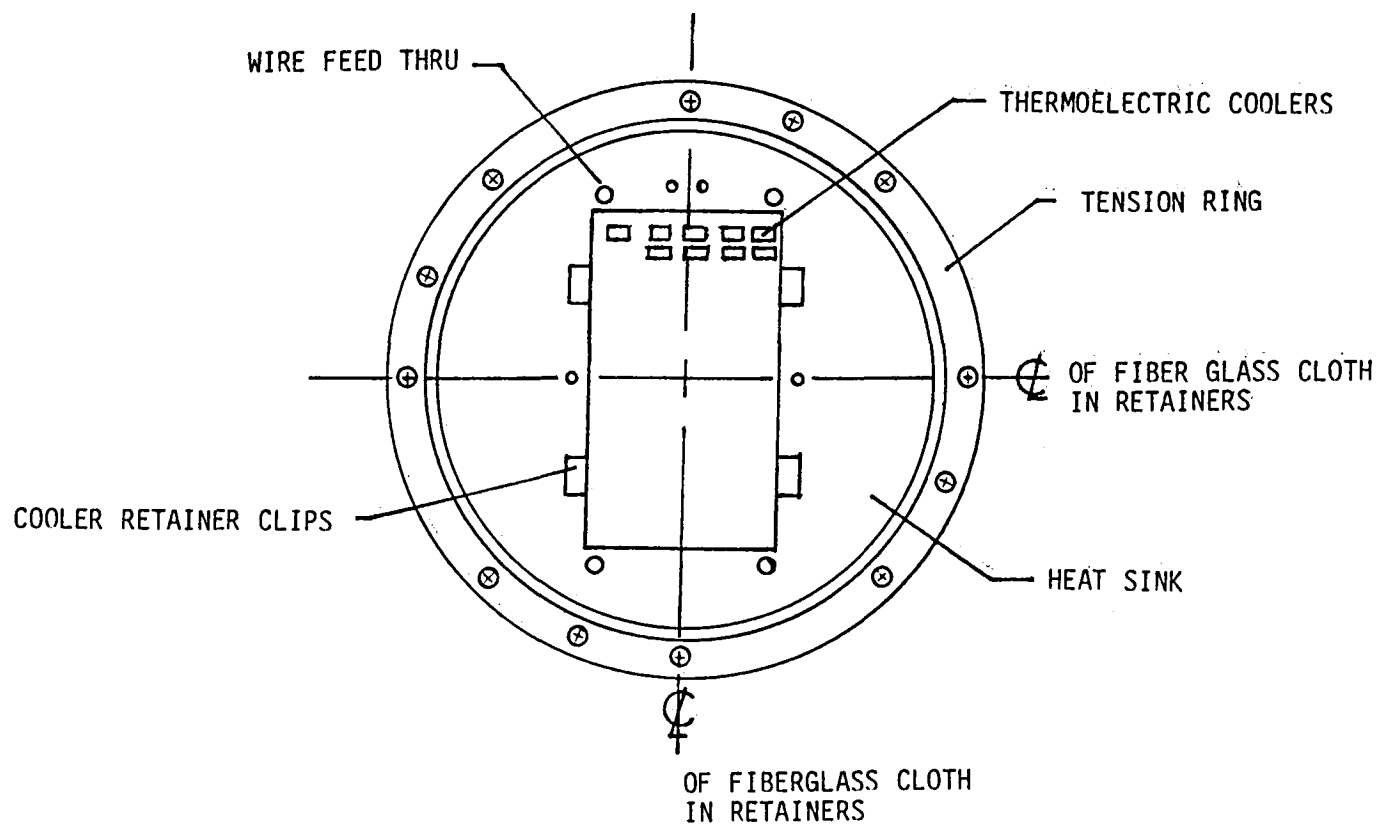


Figure A14. The sketch illustrates the alignment of the tension ring and heat sink.

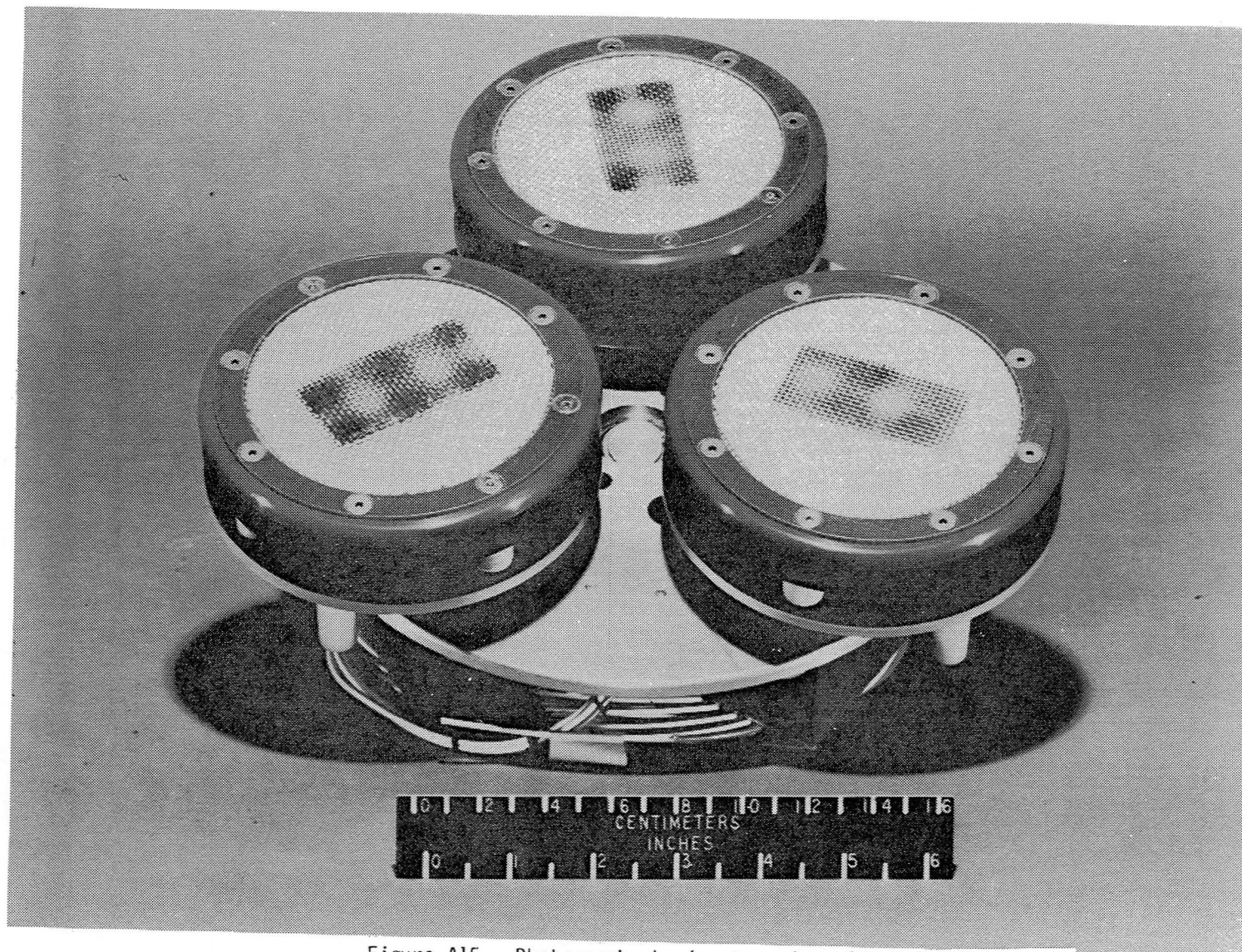


Figure A15. Photograph showing top view of completely assembled 3-pad SAA.

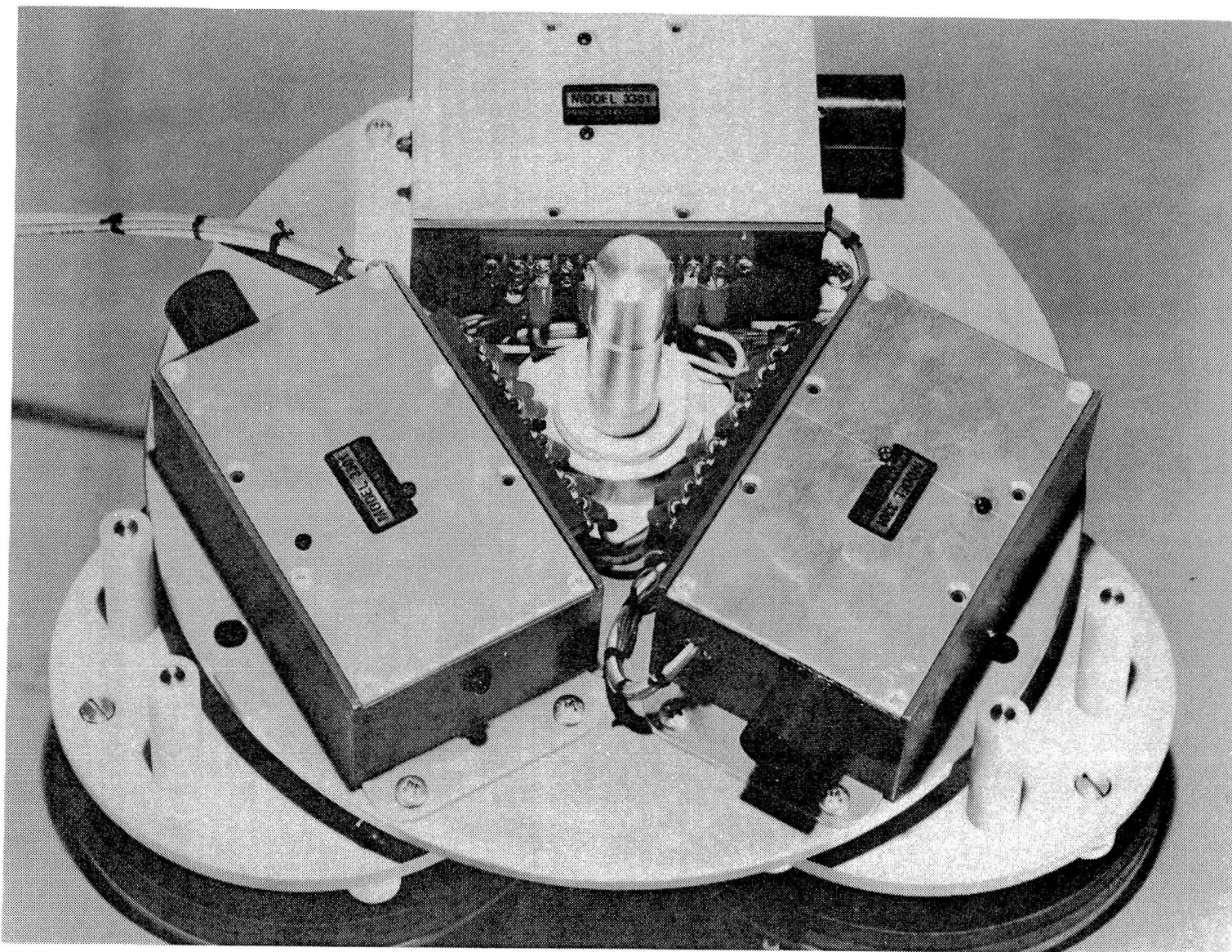


Figure A16. Photograph showing bottom view of 3-nad SAA.



## APPENDIX B

### ELECTRONIC SYSTEMS AND CONTROLS

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Electronic systems and controls necessary to heat and cool the hot melt adhesive were designed and fabricated at LaRC. Power restrictions were such that the system operate on battery (300 watt-hours). The controls for the system must be simple to operate by an astronaut in a space uniform with its bulky gloves. The system was designed to control at a preset temperature range [ $\approx 163^{\circ}\text{C}$  ( $325^{\circ}\text{F}$ )] such that the hot melt adhesive on the SAA pads softens--ready for attachment to or detachment from the Shuttle RSI tiles. Multiple attachment/detachment capability was a requirement, therefore each attachment/detachment must be restricted to very little power consumption. Also an alternate emergency heating mode for the thermoelectric coolers was included in the system design to heat the adhesive should the primary heating mode fail. Although refinement of the system is possible, the goals of the prototype SAA electronics and controls were met.

The temperature control circuit shown as a block diagram in Figure B1 is a relatively simple on-off type control circuit. An on-off type circuit was chosen primarily for its efficiency of operation. A more sophisticated proportional controller would have yielded a closer control of the temperature but would have consumed a large amount of power. Because this is a battery operated system this was considered to be an undesirable characteristic.

The circuit operates from the 28 volt battery but employs a voltage regulator to reduce the power supply voltage applied to the circuit to 15

volts. This isolates the sensitive components from the effects of gradually decreasing battery voltage.

The temperature sensing element is a thermocouple which is interfaced to a high gain instrumentation amplifier through a reference junction. A low-pass filter is provided to control the feedback loop response time and maintain the loop stability. A comparator is used to compare the amplified thermocouple voltage with a set point control voltage and to turn the switching power transistor on and off as required to maintain the desired temperature. A light is provided to indicate when the heater is off, indicating that the operating temperature has been reached.

Separate supply and return conductors are used for both the control assembly and the heater circuit, thus preventing the relatively large currents that flow in the heater circuit from inducing errors into the normal operation of the control assembly.

Figure B2 is a detailed diagram showing all the parts in the temperature controller circuit. Circuit operation is as follows. When power is applied, the relay closes and switches on the power to the reference junction. This device has an internal battery which provides voltage to operate the actual reference junction which compensates the thermocouple connections to copper wire. The use of the relay restricts operation of the battery circuit to that time when the entire circuit is in operation, thereby conserving battery life.

The voltage regulator (LM-340T) reduces and stabilizes the input voltage to 15 volts, independent of variations in the 28 volt applied voltage.

The output of the reference junction is applied to the input of the instrumentation amplifier (AD-521) which has a gain of 500. Used with the

type E thermocouple, the output voltage from the amplifier has a scale factor of approximately 35 millivolts per degree Centigrade. The gain of the amplifier is set by the ratio of resistors R2 and R1. Resistors R3 and R4 bias the negative input of the amplifier to approximate 7.5 volts. The input voltage from the thermocouple is applied differentially between the positive and negative inputs. Pin 11 of the AD-521 is an output reference terminal which allows the output voltage to be referenced to an arbitrary ground. In this case, the output reference is set by the voltage on the arm of potentiometer VR-1 and is generally at the midpoint between 15 volts and ground.

Resistor R5 and capacitor C5 form the low-pass filter which controls the loop response. These values were arrived at by experimentation and provide the best compromise between circuit stability and response time.

The comparator (LM-111) compares the output of the low-pass filter with the voltage at the arm of potentiometer, VR-3. Resistor R6 and potentiometers VR-3 and VR-4 form a voltage divider which adjusts the temperature set point. The voltage at the negative input to the comparator is more negative than the set point voltage initially. The output of the comparator is high causing the power transistor to conduct current and the circuit heats. As the temperature increases, the voltage at the negative input to the comparator increases and eventually becomes more positive than the set point voltage. When this happens, the comparator output switches low and turns off the power transistor. The LED and its current limit resistor, R9, turn on at this time and stay on until the temperature falls sufficiently for the heaters to come on again. Current for the LED flows through the heater but is not sufficient to cause any significant heating. Pin 1 of

the LM-111 is an output reference terminal which allows the output to be referenced to a point different from circuit ground. In this case the reference point is the ground return point for the heater circuit. This is nominally at the same voltage as the ground for the circuit but may carry voltage variations subject to switching transients as the heaters turn on and off. The diodes D1 and D2 raise the voltage at the emitter of the transistor and allow it to be switched fully into cutoff when the comparator output voltage switches low.

The circuit is constructed on a printed circuit board approximately 2 in. by 3.75 in and housed in a prefabricated box of dimensions 2.5 in. by 4.0 in. by 1.5 in. Connections to the circuit board are made through a small hole in the side of the box which is fitted with a grommet to protect against fraying of the wire insulation.

Figure B3 shows the interconnection of the control box and the three temperature controllers, heaters, and thermoelectric coolers. The control box has two switches which determine the mode of operation of the system. Switch S1 has three positions: the center position is an off position in which nothing is energized. In the heat position, power is applied to the temperature controllers and the heaters are energized to heat the adhesive. In the cool position, the temperature controllers are de-energized and the thermoelectric coolers are connected to the 28 volt supply. It should be noted that there is not control of the temperature in the cooling mode and it is up to the operator to turn the power off when the adhesive has cooled.

Switch S2 is a mode switch used to activate an emergency heat mode. If the normal heating mode fails to operate when it is required to heat the adhesive to "unstick" the assembly from the surface, the switch S2 is placed

in the emergency heat mode where the thermoelectric coolers are operated in a heating mode to heat the adhesive. Switch S2 merely reverses the sense of the voltage applied to the thermoelectric coolers and they "pump" heat in the reverse direction.

A list of materials used to assemble the electronic systems and controls is given in Figure B4. Additional information on thermofoil heaters is given in Figure B5.

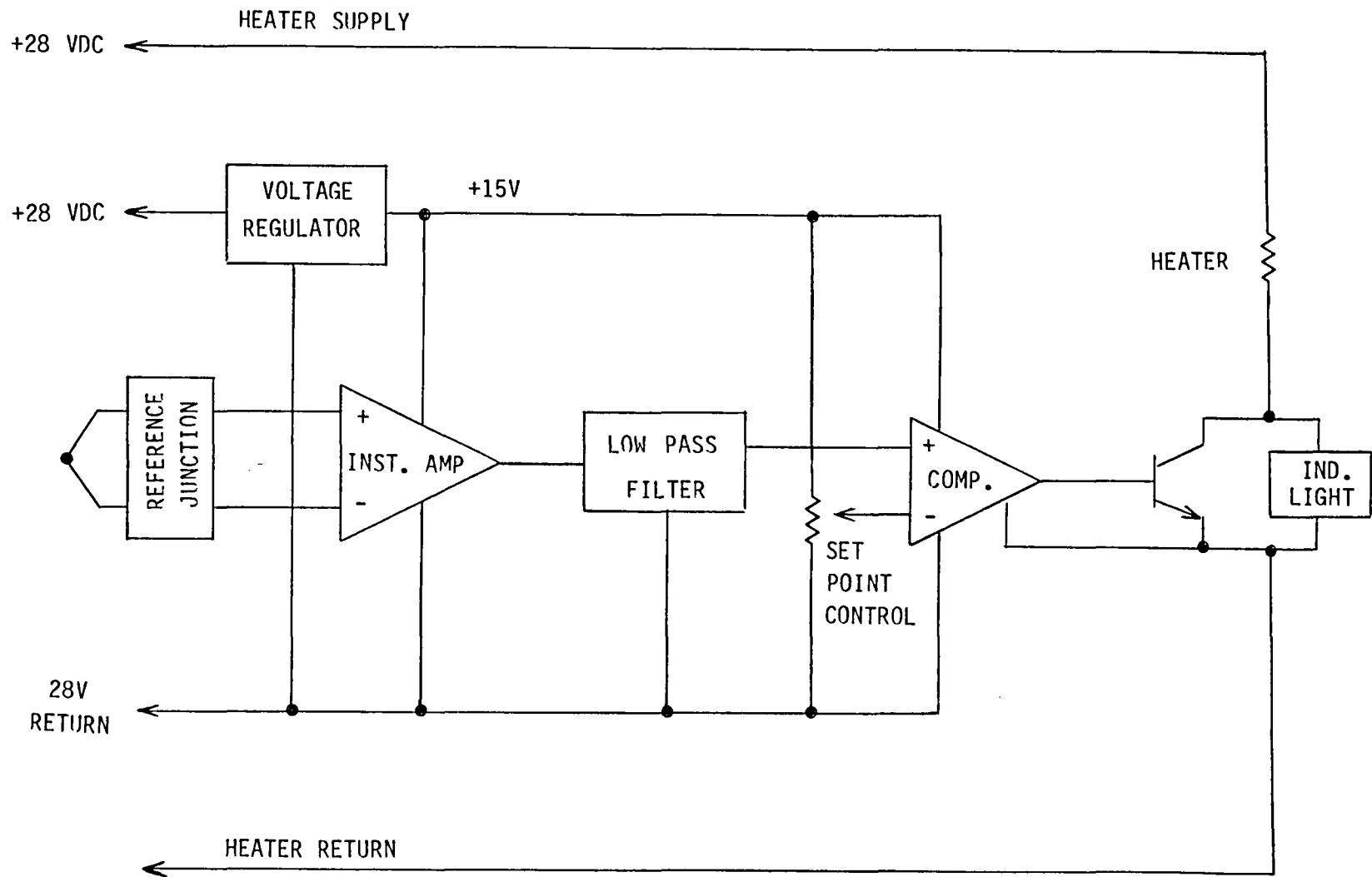


Figure B1. Temperature controller block diagram.

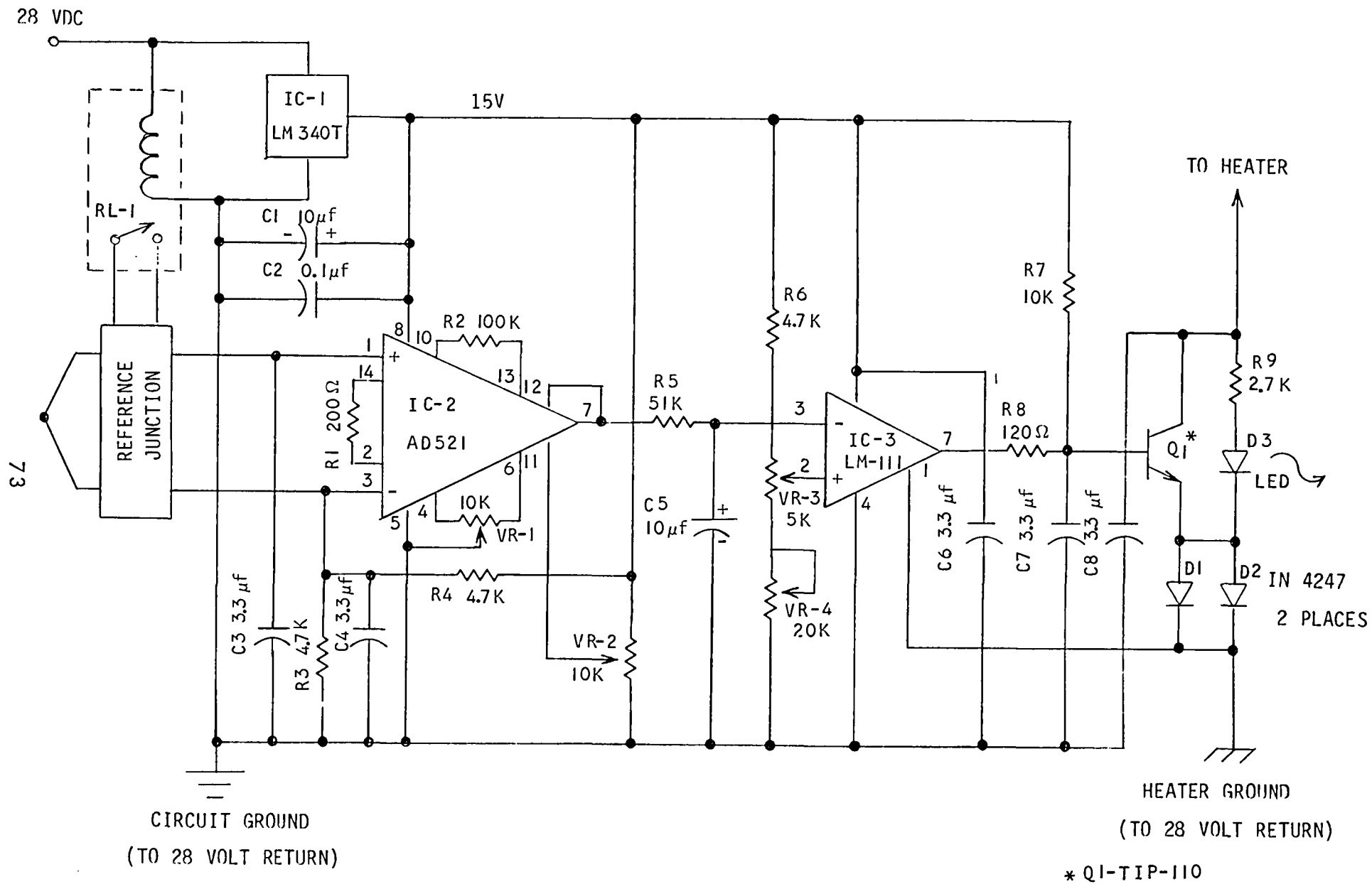


Figure B2. Temperature controller circuit diagram.

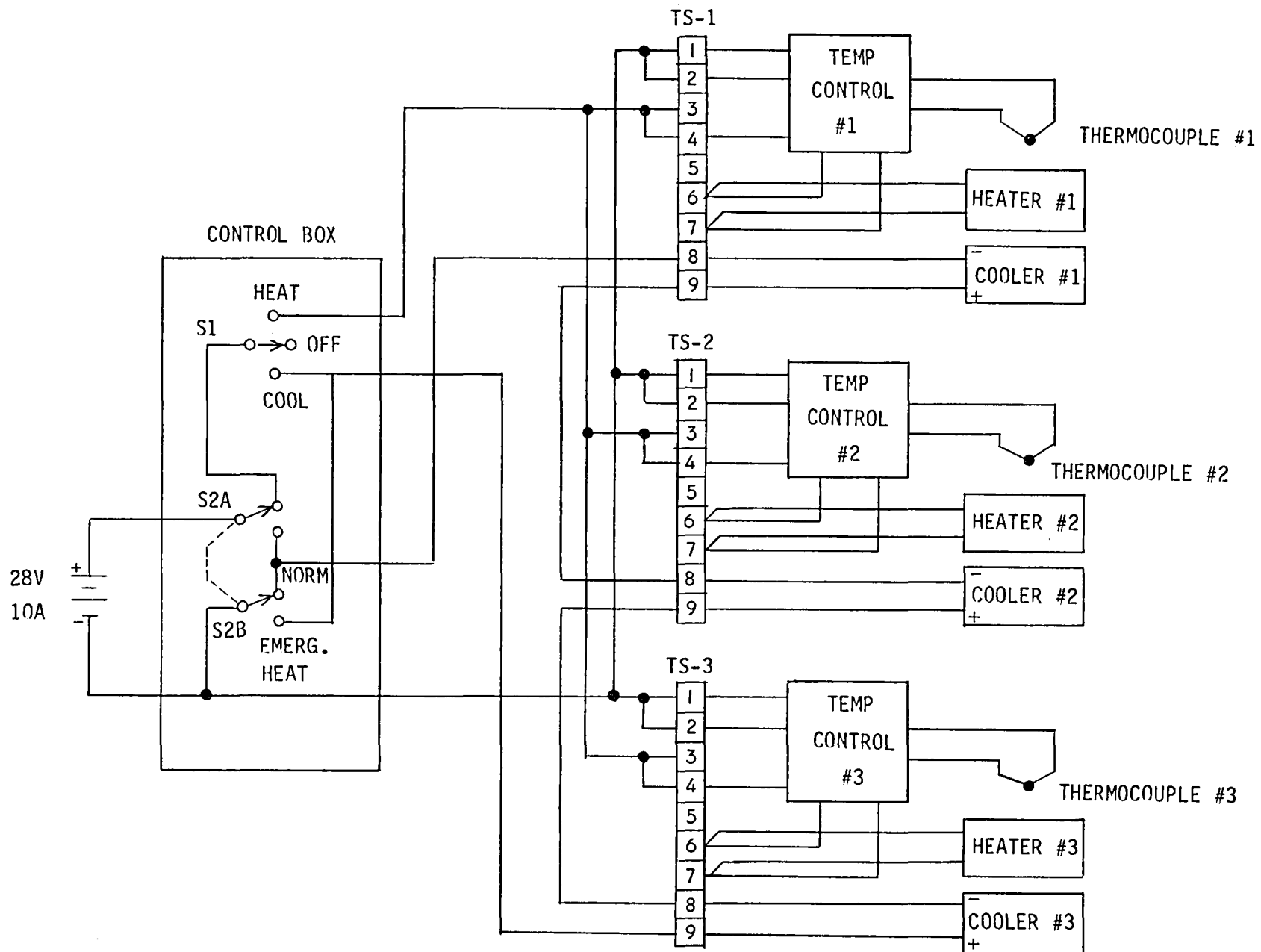


Figure B3. External interconnection diagram.



Heaters: Minco Products HK 6040-03A21.0 (three per pad)

Coolers: Cambridge Thermionic 801-1081-01

Printed Circuit Board:

R1	200 ohm,	.01% film	
R2	100 Kohm,	.01% film	
R3	4.7 Kohm,	5%	.25W carbon
R4	4.7 Kohm	5%	.25W carbon
R5	51 Kohm	5%	.25W carbon
R6	4.7 Kohm	5%	.25W carbon
R7	10 Kohm	5%	.25W carbon
R8	120 ohm	5%	.25W carbon
R9	2.7 Kohm	5%	.25W carbon

VR1	10 Kohm	10 turn
VR2	10 Kohm	10 turn
VR3	5 Kohm	10 turn
VR4	20 Kohm	10 turn

C1	10 $\mu$ F	35 volt	Tantalum
C2	.01 $\mu$ F	50 volt	Ceramic
C3	3.3 $\mu$ F	50 volt	Ceramic
C4	3.3 $\mu$ F	50 volt	Ceramic
C5	10 $\mu$ F	35 volt	Tantalum
C6	3.3 $\mu$ F	50 volt	Ceramic
C7	3.3 $\mu$ F	50 volt	Ceramic
C8	3.3 $\mu$ F	50 volt	Ceramic

IC-1 Generic LM-340T  
IC-2 Analog Devices AD-521J  
IC-3 Generic LM-111

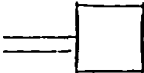
D1 Generic 1N4247  
D2 Generic 1N4247  
D3

RL-1 Teledyne Relays type 412-26

Reference Junction Omega Engineering type LXCJ-E

Q1 Texas Instruments TIP-110

Figure B4. Listing of materials used for electronic systems and controls.

BASIC MODEL NUMBER	ILLUSTRATION	RESISTANCE
HK6040-03A21	 1.5 in. 3.00 in.	21 ohms.

Thermofoils are thin laminar assemblies which may include one or more heating elements, resistance-type temperature sensors, or temperature stable resistors, arranged either separately or as an integrated circuit. The thin flexible insulations, between which the elements are bonded, are selected for their dimensional, thermal, and electrical properties; resistance to radiation, organic chemicals, moisture and abrasion. Internal element connection and leadwire attachments are normally welded for reliability.

Figure B5. Information on thermofoil heaters.



1. Report No. NASA TM-85771	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Hot Melt Adhesive Pad Surface Attachment Assembly Concept for On-Orbit Operations		5. Report Date March 1984	
		6. Performing Organization Code 505-33-33	
7. Author(s) Donald J. Progar and Bland A. Stein		8. Performing Organization Report No.	
		10. Work Unit No.	
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		11. Contract or Grant No.	
		13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code	
15. Supplementary Notes Use of trade names or manufacturers does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.			
16. Abstract <p>Langley Research Center has investigated the use of a hot melt adhesive concept to develop a surface attachment assembly (SAA) for on-orbit attachment and detachment operations for the manned maneuvering unit (MMU). The concept involved impregnation of the hot melt adhesive into a fiberglass covered pad which contained electrical heating and thermoelectric cooling devices. The polyamide hot melt adhesive selected can be repeatedly heated to its melting point in a vacuum and provided good adhesion to various surfaces, i.e. reusable surface insulation tiles, metals, and composites, when cooled.</p> <p>A number of the "needs and "wants" for the work restraint system attachment unit have been achieved.</p> <p>After a series of adhesive screening tests, Jet-Melt 3746, was selected from a group of commercially available thermoplastic adhesive candidates which met or exceeded many of the criteria established for the SAA system.</p> <p>The SAA system was designed and fabricated at LaRC with the goal of proving the concept with a working model rather than attempting to optimize all facets of the system. This system evolved by investigating alternate attachment concepts, designing and fabricating electronic systems to heat and cool the adhesive, and then fabricating electronic systems to heat and cool the adhesive, and then fabricating and testing two prototype full-size units.</p> <p>Further documentation may be found in 20 and 50 minute video tapes available from LaRC.</p>			
17. Key Words (Suggested by Author(s)) Adhesives Space Vehicle Repair Hot Melt Adhesives Shuttle On-Orbit Repair Surface Attachment Assembly (SAA) Reusable Surface Insulation (RSI) Work Restraint System (WRS) Manned Maneuvering Unit (MMU)		18. Distribution Statement  Unclassified - unlimited  Subject Category - 15	
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